MAN OF HIGH FIDELITY

MAN OF HIGH FIDELITY:

Edwin Howard Armstrong

A Biography by LAWRENCE LESSING

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To Yvonne

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Preface

THE SUBJECT of this biography, like other great inventors before him, was a controversial figure during his lifetime. The controversy did not end with his tragic death by suicide in New York on February 1, 1954.

No full account exists of the life of Edwin Howard Armstrong, considered by many to be one of the great American inventors of our time and the single most important creator of modern radio. This book is meant to fill that void. It is partisan as regards the man, whom the author as a journalist knew over a period of fifteen years and esteemed as a great man; but it is as objective as the writer could make it with regard to the history and background of his life and times.

The author gratefully acknowledges the many kindnesses and cooperation extended to him by Mrs. Marion McInnis Armstrong, the wife of the inventor and executor of the estate, and by the late Alfred McCormack, his personal lawyer and friend, who made many trenchant suggestions on the manuscript but did not live to see it in print. He is particularly indebted to them for making freely available to him without restrictions all the inventor's personal papers and records, without which this biography could not have been written. The writer also extends his thanks to the inventor's sisters, Mrs. Bradley B. Hammond and Mrs. Thomas H. Beardsley, for aiding him in reconstructing the family background. The author is also indebted for many personal reminiscences and lively details to a host of Howard Armstrong's friends and associates, including Professor Morton R. Arendt, George E. Burghard, C. Randolph Runyon, Jr., William T.

Russell, Thomas J. Styles, Harry W. Houck, Harry Sadenwater, Ernest V. Amy and John Bose.

This is in no sense, however, an "official" biography. Such opinions, judgments and interpretations of events as appear in these pages are the writer's own and are in no way to be attributed to the above sources. Armstrong was an exceedingly complex man living in a complex age. Many shadings of opinion are possible, even among Armstrong's closest associates, not to mention those hostile to him, as to the exact character of his role in our times. The portrait drawn here, with what skill and documentation the writer could muster, must rest for its validity upon the verdict of history.

L. P. L.

MAN OF HIGH FIDELITY

Chapter 1

The Attic Inventor

THE CAREER of Edwin Howard Armstrong began traditionally enough, about the turn of the century, in an attic. It was a large and comfortable room at the top of a big, gray Victorian house in Yonkers, New York, with turret and porches overlooking a wide sweep of the Hudson River and one of the better-class neighborhoods of the time, but an attic nevertheless.

By then it was deeply rooted in the American legend that all great inventors began thus. In just such a homely room a man alone might, with the aid of only his own two hands, luck and native intelligence, come upon a new idea that would not only make his fortune but move the world. Thomas Edison had begun his experiments in an unused corner of his family's farm cellar. The young Wright brothers, Wilbur and Orville, were even then building a gliding machine in a room behind their small bicycle shop in Dayton, Ohio, from which they were to go on to make the first powered flight in a heavier-than-air machine at Kitty Hawk, North Carolina, in 1903. Everywhere in odd corners of the land, boys of a curious bent were tinkering over makeshift apparatus and work tables, absorbed in pursuit of the American dream. The boy in the attic in Yonkers was spending most of his days and nights fiddling with a telegraph key and wireless contraptions.

Years later, when he had made his mark as the single most important inventor of modern radio, Howard Armstrong

was persuaded to return to his attic to pose for a picture. The room had been kept intact by the family, locked and inviolate, as most of the things in his life were preserved. Indeed, the key to the room could not be found, and Armstrong, always a man of direct action, insisted on climbing out on the steep roof from an adjoining room and inching himself along a narrow, precarious gutter to force a window into his old sanctum. He had always liked to climb about high and dangerous places, and probably had been all over the roof as a boy. Except for the dust of years and fallen plaster, the attic room was as he had left it in his early manhood. An old cast-iron bed stood in the center. Old desks and tables lined the walls. A litter of dusty filing cases, chests, papers, old storage batteries and the crude "breadboard" circuits of his early experiments covered all the surfaces and the bed. No attempt was made to tidy the picture. Armstrong posed gently in the center of it, under the sloping ceiling, a tall man, bald and past his prime, glancing at a long-forgotten paper with a look of stoic pride and brooding intelligence on his mobile features.

It was in many ways a sad picture, for behind it moved a strange and turbulent life. The inventor had made his fortune, as the legend had foretold. He had won medals, honors and encomiums for his inventions that even then were filling the world with music, sound and the miraculously instantaneous transmission of human intelligence. His basic contributions to radio were three, and together they constituted the landmarks and the history of radio. The first was the regenerative or feedback circuit (1912), which took wireless telegraphy out of the spark-gap, crystal-detector stage into the radio era of amplified sound. The second was the superheterodyne circuit (1918), which underlies all modern radio and radar reception. The third and subtlest conception of all was wide-band frequency modulation or FM radio (1933), a nearly static-free system of high-fidelity broadcast-

ing that revolutionized the reproduction of sound and opened a development in communications and the auditory arts that is not yet ended. A fourth invention, known as superregeneration, made in 1922 but not widely used, may yet prove as basic as these three.

But the inventor had wanted something more, something hard to define. A perfection, perhaps, not attainable in this life, or some non-material fulfillment only suggested in his early yearnings, or perhaps simply justice. Hardly any of his victories had been clear-cut or generously conceded. Long after they seemed safely won, they had been dogged by ill-luck and malicious detraction. Between the rather simple dreams of the boy in the attic and the long thoughts of the man who stood there for his portrait, something of a changed and wounding nature had happened to the American dream.

The world had grown exceedingly complex. More and more the individual inventor was being overshadowed by the mounting establishments of science and by large technical corporations pursuing organized research with teams of investigators and battalions of patent lawyers. The old American idea of a simpler day that all creativeness and ultimate power resides in the individual was being shuffled out of the way. Armstrong grew up just as the big industrial laboratories were spreading. Most of his life was spent in heroic defiance of their overweening claims. He fought hard and stubbornly to maintain his independence, with a sense of integrity sometimes painful in its extremes. At times his life appeared all fury and fractiousness. Nearly half of it was spent in the law courts in some of the longest, most notable and acrimonious patent suits of the era. Under these pressures, Armstrong became a complex man, shy yet aggressive, worldly yet never losing a certain original naïvety, the charm and mystery of genius. At the end he knew that he was fighting an implacable turn of events. The day of the lone attic

inventor was waning. He was among the last of the breed.

Armstrong's working life spanned a half-century of change more rapid and violent than almost any like period in history. Even those who have lived through it find that it requires a feat of memory to cast themselves back into the world of fifty years ago, so remote does it appear in time. Almost none of the now commonplace apparatus of modern life—the internal combustion engine, the airplane, the motion picture, the electric motor and dynamo, and all their appurtenances—had yet appeared in force to give the new century its peculiar shape and tempo. Within a few short years, however, the accumulated discoveries of the nineteenth century debouched a stream of inventions that suddenly contracted all time and distance and unleashed on the world an unprecedented range of new powers. New industries sprang up on these inventions and swiftly grew to giant size. Invariably, each new invention was hailed as a new instrument to draw the world closer together in trade and amity. This early optimism soon proved shallow and the hopes of a better, more rationally organized world mostly vain. No age suffered a more precipitous drop into disillusionment. But, in a sense never before experienced, the spate of physical change in the first half of the twentieth century more deeply transmuted the world and the possibilities of human life in it than any previous force in history.

Ironically, Howard Armstrong was one of the leading architects of this change, laying the groundwork for that system of mass communications and the control of large forces by a tiny flow of electrons that are characteristic of the age. Radio and electronic techniques came to be the impalpable nerve fibers of a century moving ever faster over the earth, in the water and through the air, complementing and accelerating this mechanization and influencing every aspect of life. Though he carried over some of the ideals and viewpoints

of a previous era, Armstrong was almost wholly a man of this century and intimately embroiled in it.

Try as he might, Armstrong could not mold himself into the patriarchal image of an Alexander Graham Bell, an Eli Whitney, a Samuel F. B. Morse, a Thomas Edison, inventors of an earlier, individualistic age whose composed features stare at us equanimously from textbooks with the grave directness of trade marks or household gods. He was of a different stamp, modern, over-specialized, sensitive. The age was not conducive to either composure or security. Almost nothing in his manner or appearance suggested the popular, assured figure of a great inventor. With his smooth round head, bald almost from youth, and his powerful big frame, almost invariably clothed in conservative business suits, the uniform of the age, he might have been taken for a banker or any anonymous businessman. Only when his reserve was pierced was it possible to glimpse the driving force of his mind.

From time to time, Armstrong's battles and exploits drew the attention of the press, but some quality in the man or in the times withheld from him that instant recognition that is fame, fleeting or enduring. He was not indifferent to fame, and that, in the end, was part of the hurt. Though his inventions were fully as great as those of his predecessors, no touch of folk myth came to make of him a hero. The loud floods of advertisement passed him by. His name and figure tended always to slip into the background, in the constant stream of new developments, most of them far less basic than his own. Probably no great American inventor of recent times is less popularly known or understood.

The times are not propitious for the recognition of great, rebellious or unorthodox talent. They are never too hospitable, but rarely have they been so bad as at present. Large impersonal forces are loose in the world, in this country as in more tyrannous parts of the globe, sweeping aside the indi-

vidual of high merit in pursuit of some new corporate, collective and conformist destiny. These forces, and other ills more personal, crushed Armstrong in the end, as they are crushing others. But not before he had lived a full life of great significance and poignancy for the times.

Chapter 2

A Child in the Nineties

NOTHING OF THIS portentousness is visible in the face of the small boy who, just before the turn of the century, may be seen at play in a series of browned and fading vignettes pressed into the leaves of family photographic albums. This is all that remains of the light and substance of those far-off days. Yet the fading prints still retain some of the sunlight of a happy childhood lived without eventfulness in the long autumn of the Nineties, in middleclass America before the world turned cold and violent.

He sits smilingly on a tricycle, before a long flight of brownstone steps, surmounted by a heavy door with a gleaming brass bell-pull. He stands, bright and self-possessed in tight knee-britches, beside a prized set of toy, cast-iron trains. He climbs, with middy-collar flying, a high hill in a country landscape. He poses, quizzical and teasing, with his younger sisters, Ethel and Edith. One sunny morning in 1896, he and the youngest, Edith, pause in their Sunday best for a picture that preserves the look and aroma of the era. Edith wears a long, plaid, taffeta dress with tiny leg-o'-mutton sleeves and a large flowery hat. Howard, then going on six, wears a short, dark sailor outfit, a flat felt boater and an open grin. His face in these early years is round, open and quick with joy, though the underlip is stubborn and the eyes, more often than not, are level and grave.

It was a tranquil, genteel, late-Victorian household into which Edwin Howard Armstrong was born, December 18,

1890, in a neat brownstone house at 347 West 29th Street in the old Chelsea district of New York City, the first child of Emily and John Armstrong. His father was associated then and for many years thereafter with the Oxford University Press, at that time devoted mainly to the sale of Bibles and standard classical works. John Armstrong himself had been born on 19th Street of an old New York family and had gone to work early at the Oxford Press, eventually rising to become vice president in charge of the American branch. Howard's mother, whose maiden name was Smith, was the strong, gentle, deeply religious daughter of a prominent business family in the neighborhood. The Smiths had their family home only a block away on West 30th Street, and together the Smiths and Armstrongs formed a dense phalanx of grandparents, uncles, aunts and auxiliary relations around all of Howard Armstrong's boyhood.

John Armstrong had met and married Emily Smith in the old North Presbyterian Church at 31st Street and Ninth Avenue, an institution in which the Smiths had been exceedingly numerous and active for nearly half a century. John Armstrong himself was a trustee of the church. He was then a tall man of imposing presence, with a dark, luxuriant moustache in the style of the period, a poetic turn of phrase, a flow of banter and an excellent speaking voice, much in demand for leading prayers at church meetings and for addressing conventions in the book trade. Some of his speeches are still extant, carefully written out in fine Spencerian script. Once a year he journeyed to England to confer with his superiors, bringing back an aura of foreign travel, of the world outside and of communion at the fountainhead of Victorianism.

The most pervasive element in the Smith and Armstrong families was school teaching. Emily Smith was a graduate of Hunter College in New York and taught in the public schools for ten years before marrying John Armstrong in 1888. John Armstrong had lived on 19th Street with two

maiden sisters who were for many years teachers in the public schools. Other school-teaching aunts and uncles, great uncles and aunts were pendent all over the Smith family tree. There was therefore a strict but loving air of pedagogy throughout the two adjoining households that kept a young man on his toes. "Quick, boy!" was the invariable greeting of his great uncle Charles Frederick Hartman, who was principal of New York Public School No. 160. "How much is nine times five, minus three, divided by six, times two, plus nine?"

The Armstrongs did not remain long on 29th Street. New York was then rapidly changing. Old neighborhoods were being inundated by rising trade and immigration, and residential areas were being pushed further and further uptown and out toward the suburbs. The old North Church was forced to seek new quarters uptown and the Smith family followed it. John Armstrong moved his growing family out of the crowding Chelsea area in 1895, first to another substantial brownstone at 26 West 97th Street, then, in 1902, to the big gabled house overlooking the Hudson at 1032 Warburton Avenue, Yonkers, an address always referred to later by friends and associates as simply "1032," as if it were a magic number able to evoke at once the exact place and the events that transpired there. The Smith family moved up to Yonkers with them, into a big house on a wide lawn next door.

The family life that went on in Yonkers as in New York was on a scale of warmth and closeness that has passed almost out of existence, if not out of mind. Lacking the mobility and distractions of a later day, the family centered on itself. All occasions were celebrated with great vigor amid large congregations of relatives. Family dinners of forty or fifty were nothing out of the ordinary. Huge preparations went on in the kitchens in a cheerful clatter of steaming kettles, dishes and female gossip. Sundays were holy terrors. Up early to be carefully brushed and dressed for morning services, then back to church again at two for Sunday school, and

again at seven and eight for Christian Endeavor and vesper services. The Smiths practically ran the church. Grandfather Smith, who always regretted not having entered the ministry, was leading elder, choir master and superintendent of the Sunday school. Grandmother Smith supervised the infant class. Uncle Frank presided at the organ, Uncle Will was a deacon, and Aunt Rissie and her sister Emily taught in Sunday school. The children followed in the indefatigable wake of their elders, shoes blacked, cheeks scrubbed, hair neatly wetted down or curled, all ruffles and pressed pants and Sunday decorum.

This was the little world of the Nineties, the long calm before many storms. Later generations were to find it at once indescribably funny and gross, nostalgic and revolting, gay and sad, perhaps because they were to break from it so sharply. The men walked about in narrow trousers and high, black, cast-iron derbies. The women wore high, starched shirtwaists over deeply corseted bosoms and trailed long skirts of heavy-textured stuff. They lived in homes heavy with fretted porches, Turkish rugs, fumed oak and blood-stained mahogany. The leading citizens were all very solid. Nearly everyone was connected with business. William McKinley, the Sound Money and High Tariff man, had come to rule in the White House, and if all was not well with the world, at least the world was kept at a distance, walled out and far away.

Nights were illuminated by the greenish glow of the gas mantle, for the electric lamp was still a luxury and only a few main streets lay harsh and bare under the glare of arc lights. The Chicago world's fair of 1893 put on a dazzling display of the new electricity, but men of substance were dubious when a leading inventor, Nicola Tesla, predicted that it would soon be as available to everyone as tap water. The first electric trolleys were careening around corners, but the streets were still given over largely to the horse and car-

riage and dray. The gasoline buggy was a gaping curiosity wherever it appeared. Charles E. Duryea had begun manufacture of the country's first, high-hipped automobile in Ohio in 1891, but as late as 1900 weighty opinion could be obtained in Wall Street that it would never amount to much.

The age was running to complacency after the ponderous building up and concentration of industry following the Civil War. It was full of civic pride, lush sentiments and too much food. Financial panics briefly shivered its self-esteem in 1893 and again in 1897. Dark rumblings of revolt were heard from farmers and laborers. Teddy Roosevelt and the muckrakers were in the wings, ready to thunder and gnash their teeth theatrically at the Trusts. And in the distant Philippines the country's first adventure into imperialism was raveling out dustily and ignominiously in the hills. But in the long calm that ended the great, vulgar, vigorous, seminal, sublime and sanctimonious nineteenth century, nothing seriously came to disturb the middleclass in its belief that Progress must move ever forward at a rate proper to its comfort and accumulation of wealth. And, indeed, a vast ferment of ideas and discoveries made the new century dawn with immense promise.

Howard Armstrong was a schoolboy in this period, and its yeasty influences penetrated and shaped much of his life. But of that boy's life before the turn of the century little now survives except traces of memory and a few outward facts. He was brought up with firm rectitude in that stern yet practical Presbyterianism that combines sanctity and hope of heaven with getting ahead in the world. He was sent to public grammar school on West 89th Street, where he was a good though not memorable student. He was enveloped in the life of the family. It was a quiet, gregarious, genteelly cultured but by no means austere household, with many books about, a lively interest in domestic affairs and an occasional visiting dignitary from the great English press. On the scale of the

times it was neither wealthy nor poor but comfortably well-to-do. Thus insulated by happy middleclass circumstances, the boy's early life appears all soundless and serene behind the veil of childhood.

Only one sharp rent appears in the curtain. In his ninth year he suddenly came down with St. Vitus' Dance. The family account of the illness closely links it with a blow on the head received while out at play one wintry day, when a companion threw a shovel at him. The blow may be regarded as only incidental, for St. Vitus' Dance is now generally believed to be associated with rheumatic fever and other acute but then little recognized childhood infections. The infection in some way short-circuits the motor areas in the brain, producing those twitchings and violent, involuntary motions that give the disease its name. Usually, it runs its course in a few weeks or months, subsiding as mysteriously as it came, leaving behind only a nervous tic or some slight change in personality. Occasionally it may leave deeper, hidden damages that appear only later in life. In Howard Armstrong's case the attack was severe enough to keep him out of school for two years, carefully nursed at home by his mother. His great aunt Rosina, who was no longer teaching school, came over every day throughout this period to tutor him, so that when he again returned to school he was, with almost no effort, soon abreast of his class. This illness was the final impelling force that moved the family out to Yonkers, for there Howard would be able to get out in the sun, the fields, the clean air and regain his strength. He pulled out of it all without apparent harm, but with a tic that he would bear for the rest of his life—a habit of hitching a shoulder forward and wryly twisting his neck and mouth whenever he was excited or under stress.

From the beginning, Howard had been what his aunts and female relatives called "a serious child." After his illness he was even more thoughtful and withdrawn. The effort to

control his muscular movements sharpened a physical courage that was to delight in pitting itself against high places and in all tests of endurance, as if by daring and indomitable will his whole life was to be proved. The long illness threw him back upon himself, suddenly differentiated him from other beings and implanted the idea of differentness. Because of his slowly mending physical tic, he was painfully shy. He played much alone. He was early interested in mechanical things, especially in discovering how they worked. His first and never discarded passion was for railway trains. When, a little later on, his first toy train, a side-winder, was replaced by an electrical model, running off a battery, his delight and explorations knew no bounds. He spent hours in a maze of tracks and wires.

The illness receded, as such things will, into an episode, and life went placidly on. From his earliest years the family was in the habit of spending the summers away from sultry New York. Summers were spent upstate on a big farm near Richfield Springs, known as Derthick Farm, owned and operated by the John Derthick family, for many years close friends of the Smiths. These interludes formed a memorable part of childhood. There were animals and birds and hills and haymows and luncheons under the trees and other assorted enchantments into which the children sank like yearlings into a fragrant meadow. John Armstrong came up for vacations and occasional long weekends to add to the endless fun and family chaffing. An ardent tennis player, he built a court and put the children on it almost as soon as they could lift a racket, holding that tennis supplied nearly everything needed to develop a quick mind and sound body. Howard took to tennis as to mechanics, with a driving will and, as he waxed stronger, a cannon-ball service. Altogether, some ten summers were passed thus, until, to be nearer and more accessible to Yonkers, the family shifted its summer operations eastward to the shores of Lake George. But nothing later

matched the memories of Derthick Farm, so redolent of the long, happy retrograde of leafy, childhood summers that ever afterwards the children spoke its name as if pronouncing a spell.

By then the new century was well begun, the family was moved to Yonkers, and Howard was beginning to sprout into gangling adolescence. Many parts of his character were already firmly set. His first twelve years had been spent in New York and he was to retain ever after the accents and loyalties of the New Yorker born and bred. The new house on the heights in Yonkers had its attractions—grass, trees, spaciousness and a majestic view across the Hudson to the Palisades, gleaming in russet and copper on the further shore—but these were enhanced by fast train service directly below at the river's edge from Graystone Station to New York. He was still interested in trains. He was also interested, as a biographical note by himself later revealed, in running, skate sailing and climbing to high places, a sport for which the precipitous Hudson River Valley was ideal. By then, too, he was reading widely, mainly tales of adventure and discovery and the more heroic passages of American history. And always there was tennis, in which he came to hold as firm a belief as his father, and that steady passion for exploring mechanical contraptions, for which there were no precedents on either side of the family.

There was hardly anything unusual in all this. Indeed, up to this point, his life might have been counted a typical American boyhood, typical of his class and station, in an age when the machine and mechanical aptitudes were developing on all sides. Except for a certain gentle freshness, directness and boldness in him, that might have been no more than the brief bloom of youth, he was in no way distinguishable from the offspring of other comfortable families in that tranquil time and neighborhood. Yonkers was then a growing satellite of New York, a forerunner of those endless sub-

urbs that, with the ascendancy of the automobile, would stretch out and out on various levels of economics and fashionableness, all alike neat, sterile and monotonous. It was an atmosphere productive of many able, commonplace men, broken to conformity and the utilitarian professions, but barren, if not inimical, to the imagination and the creative faculty. It was unlikely ground, those shady lawns and suburban porches, for the lightning stroke of genius.

Chapter 3

The Boy Wireless Operator

THE FIRST STROKE of lightning came in 1904, when John Armstrong, returning from his annual visit to London, brought Howard as a gift *The Boys' Book of Inventions.* This volume was supplemented in the following year by another, earnestly requested, entitled *Stories of Inventors.* Their effect on the boy was electric, if not electronic, for in one swift reading they set the whole course of his life. Then and there, at the age of fourteen, he determined to become an inventor.

At first he was a bit hazy as to just what field of invention he would enter. He was torn between an interest in wireless telegraphy, which had burst upon the world only ten years before in 1895, and in X-rays, those subtle emanations which had been discovered in the same year by the German physicist Wilhelm Roentgen. For a time he pored over everything he could find on both subjects. Not long after entering Yonkers High School in 1905, he made up his mind. "Somehow, for reasons I cannot recollect," he wrote much later, "the decision favored wireless."

This decision may have been influenced as much by solid practical considerations, already strongly developed, as by more romantic, idealistic ones. Two figures in his books had particularly inflamed his interest. One of these was Michael Faraday, the English blacksmith's son and poor bookbinder's apprentice who, in 1831, discovered electrical induction—the principle of the dynamo—and laid much of the founda-

tion for the electrical power industry, just then beginning to come to the fore. Faraday went on to become a towering figure in physics, electromagnetism, chemistry and the world of science. His powerful, unschooled mind, which moved intuitively among electrical abstractions as if they were visible currents of matter, so impressed young Armstrong that he took the great Victorian as his lifelong model and guide.

The second figure to rivet his attention was that of Guglielmo Marconi, a contemporary with an entirely different background from Faraday's, but with similar powers of mind. It was Marconi who, in 1895, experimenting with the mysterious "Hertzian waves" discovered a few years before by the German Heinrich Hertz, had been the first to send these electromagnetic ripples purposefully through space for any distance. As recently as 1901 he had succeeded in sending the first wireless signal across the Atlantic from Poldhu, England, to St. John's, Newfoundland. He was even then pushing his experiments further, organizing wireless companies and spreading the excitement of wireless through the international air. Marconi himself was a dashing figure, the son of wealthy Irish-Italian parents, educated at the ancient University of Bologna. He moved about in some of the earliest and fastest Continental motor cars, and conducted some of his later long-distance experiments from his rakish private yacht, the *Electra*. The Italian government made him a Marchese, and he was soon to be honored for his discoveries with the Nobel Prize in physics.

To the youth in Yonkers, the life of invention held out alluring promises. In particular, wireless was so new and unexplored an art that it seemed to offer a trackless territory in which even a boy might make discoveries. It was not merely the surface glitter of a Marconi that attracted him, though that rich life of adventure, raising an antenna kite in a gale over Newfoundland and cruising the Cape Verde Islands to catch some faint signal from beyond the antipodes, was in

aching contrast to the placid life of Yonkers. Beside this must be placed the stern, square-jawed visage of Faraday, beckoning him to the long life of the inquiring mind. In the high attic room on Warburton Avenue, in the turret under the cupola roof with its sweeping view of sky and rolling river, as from a captain's bridge, the boy hugged these figures to him and burned to set off into the unknown. Where did the tinder come from for such a spark to ignite? The geneticists do not yet say.

Soon after these incendiary occurrences the big attic room in Yonkers began to fill with hand-wrapped spark coils, homemade interrupters, iron-filing coherers and other esoteric trappings of the early wireless telegrapher's art. At all hours of the day and night then the steady, staccato chatter of telegraph key and buzzer might be heard drifting down from the top floor. The family nicknamed him Buzz, and it became difficult to get him down for meals or for any of the usual family functions. He discovered a rich source of telegraphic lore in the neighborhood in the person of one Charles R. Underhill, an engineer and sometime inventor for the old American Telegraph Company, whom he avidly sought out and talked wireless with by the hour, beginning a friendship that was to last for many years. Underhill was a lucky find, for he not only had a sound and basic understanding of electrical and wireless matters but he had the patience to communicate it. He was the author of a handbook and several texts, which Howard prized, and he gave Howard several pieces of apparatus which were difficult for a boy to get hold of, acts of kindness never to be forgotten.

Other boys in the neighborhood and in the whole eastern area were beginning to be gripped by the wireless craze. There was Bill (William T.) Russell over in Hastings-on-Hudson, Tom (Thomas J.) Styles, who lived not far from the Armstrong place, and Randy (Carman Randolph) Runyon, Jr., who in 1908 had built one of the earliest amateur wireless

stations in the area in his home at 87 Locust Hill Avenue, Yonkers. Howard made lifelong friends of this trio, joined later by others, and he was soon a legend among them. They communicated by Morse code, met casually at one another's homes and filled the air with the impenetrable jargon of wireless. Howard easily took the lead. His grasp of principles even then was astonishing. And he had about him an enigmatic quality, an unpredictableness, a quiet air of derring-do which, then as later, fascinated and attracted nearly all who came to know him.

He first met Runyon one day in 1909 when he dropped over to Locust Hill Avenue to have a look at the station he had been picking up on his wireless set. Howard sat down and for two hours discussed, with complete absorption and a running diagram drawn on an old piece of paper, a transformer he had built according to some large industrial design. Runyon could not even begin to follow him through the mazes of the diagrams, the formulas and calculations that went with it. "The only trouble with it," Howard said finally, "is it's too big to get out of the house." Runyon was then about to enter Cornell University and did not see much of Howard until after his college days and the great war which was destined to interrupt many young men's lives. Even in the gregariousness of boyhood, Howard was absorbed in his own pursuits in his own way.

On another day he appeared at Tom Styles' home to borrow some heavy glass Leyden jars, for what purpose he did not say, and proceeded to lug them up the long steep hill to his own place. Leyden-jar condensers—tin-foil lined glass jars storing static electricity, charged by rubbing a brass ball and rod in contact with the inner foil—had figured in many of the earliest experiments in electricity and were still one of the few readily available sources of heavy electrical discharges. He had some private need for such jolts of power. For weeks the jars were strung out in series in the attic corridor, being

laboriously charged and discharged to carry out his experiments. On another occasion, he got Bill Russell to help him build several big antenna kites, with which he sought to improve reception. These were no ordinary kites, but sturdy structures seven feet tall, requiring a windlass to reel them in and out of the upper-story windows on Warburton Avenue. They were invariably flown in the stormiest weather. When the wind was high enough, they were often left tethered outside to fly through the night.

His measures to gain more knowledge were invariably like that, direct and massive. When, in 1910, he set out to build a permanent antenna mast of his own, it had to be the highest in the region, and his building methods were for months the talk of the neighborhood. First he set two closely bolted two-by-fours upright in concrete in the lawn. Then, using a block-and-tackle and a bosun's chair, he hauled himself and another length of two-by-fours to the top of this, tied himself fast and clamped the second length upright on the first. A second rigging previously attached to the top of the new section was ready for the next operation. Thus he moved up by stages, running heavy guy wires out at intervals to act as braces, until he had raised the mast, almost by his own bootstraps, some 125 feet in the air. His only assistant was his youngest sister Edith, whom he called Cricket, who helped in holding the guy wires and in passing up paint when he got around to painting it—inevitably getting a partly filled bucket of paint on her head before the operation was over. For many years the mast remained a landmark in the area. Howard liked nothing better than to haul himself to the top of it in his bosun's chair, a favorite mode of transportation, to make adjustments or simply to look about.

One day a lady in the neighborhood telephoned his mother to ask whether she knew that Howard was working at the top of the mast in such a high wind that the tip was actually bending. It made her nervous to watch him, she said.

"Don't look then!" said Mrs. Armstrong, who was as indomitable as her son and trusted him from an early age to be as sensible and self-reliant as herself.

Howard Armstrong had entered the new field of wireless in just those crucial years when the whole future of wireless communications was thus laboriously to be decided. Boys sat for hours with headphones clamped to ears, straining to hear and transmit the stuttering dots and dashes of the Morse code. Nothing more intelligible was to be heard from the crude, discontinuous spark-gap transmitters and even more primitive receivers of the day. The receiver usually consisted of a coherer, a tube of metal filings that suddenly cohered and passed a feeble current when struck by a high-frequency signal from the air, but which had to be tapped to loosen the metal particles in order to receive the next signal. To hear these weak signals, operators wore painfully tight earphones. Frequently they had to hold their breath, for often the mere act of suspiration was enough to drown out those ethereal whispers from outer space. Howard had persuaded his family to allow him to move his bed into the attic so that he could listen far into the night when things were quiet and when, for some unknown reason, reception was at its best.

Even at best, there was little to listen to through the sough and surge of atmospherics, only a few commercial and military wireless stations, an occasional ship at sea and the banal, high-keyed stutterings of fellow amateurs in the immediate Hudson River community. It was in these long vigils, however, that Armstrong developed an ear remarkably sensitive to small sounds in the ether, to the subtle nuances and small effects of changes in his equipment. Late one night in 1908, in his senior year in high school, he roused the whole family to come and listen to the faint, heady signals he had pulled in from the Navy station at Key West, Florida, signals that had invisibly winged their way some 2,000 miles through the empty, silent reaches of the night sky.

The family was tolerant of, even if it did not quite understand, everything that went on in the attic. Howard drew his willing younger sister Cricket into the tedious job of winding tuning coils, which he required in interminable lengths and varieties, but otherwise he went his own mysterious way. School was quite subsidiary to his one absorbing passion. He was quick enough to make better than average grades, but, except in the sciences that impinged on his interests, he was rated only a fair student. He was best of all in algebra and solid geometry, high in advanced drawing, chemistry and American history, but only fair in physics. He got on famously with Frank Baker, his physics teacher, however. Baker allowed him to build a wireless receiver and antenna high atop the school that was still a proud part of the physics department's apparatus fifteen years later when Howard had overleaped all that was then known about wireless.

He loved to build and to tinker with all kinds of mechanical things. Children in the Warburton Avenue neighborhood brought him their broken toys, for the "Armstrong boy" liked nothing better than to repair them. He had a kit of tools that, occasionally of a Saturday, he would tote over to a nearby highway, settle himself on the grassy roadside and wait about for hours, dreaming of wireless, on the chance that one of the cranky cars of the period, just beginning to appear in numbers, would break down and he could help in the repairs. One of his aunts discovered him there one day and complained to his mother that the neighbors would begin thinking her son was crazy. He still found time for tennis, training himself almost as rigorously in it as in wireless and becoming captain of the Yonkers High School team. He also gave over hours at a time to volleying a tennis ball at his sisters to improve their back-strokes, which he regarded as an indispensable part of their education. Meanwhile, the family life went on much as before, with its holiday gatherings, church activities and long summers in the country,

shifted now to Lake Bomaseen in Vermont, where the tennis was intensive.

The religious atmosphere still prevailed. One of Howard's friends, invited to stay to lunch one day, felt constrained to fill with chatter the long silence as they sat down to the table. When he ran out of material, Mrs. Armstrong, who had been waiting patiently, quietly said grace, not perfunctorily but at sober length. It was difficult to know what Howard thought of all this, for he was by then remarkably self-contained and no longer outwardly religious. Over his work table in the attic hung a framed and illuminated Biblical text, a gift from his mother, that read: "Call Upon Me in the Day of Trouble: I Will Deliver Thee." Sometimes as he was sweating over a stubborn problem in his maze of wires and paraphernalia, he would cast on this text an ironic and humorous eye.

The goal of all operators then, amateur or professional, was to find some means of sending out and receiving wireless signals stronger, clearer, more continuously and over greater distances than ever before. It was the particular dream of amateurs, who, as so often in the sciences, were carrying on the most daring explorations, to be able to get signals over unheard-of distances. A few dreamed of sending out speech and music over these invisible waves, but reliable transmitters and, more importantly, sensitive receivers were quite lacking for broadcasting and receiving the continuous-wave power necessary for this feat. In 1906, Professor Reginald A. Fessenden of Harvard University, a little recognized pioneer in the field, managed by means of a more powerful continuous-wave electric alternator of his own design to send out the first historic, halting broadcast of this kind. On Christmas night, 1906, wireless operators on ships plowing the North Atlantic were startled to hear in their headphones snatches of music, breaking through the colorless dots and dashes, from Fessenden's experimental station at Brant Rock, Massachusetts.

This was later duplicated by the amateurs, whose ranks were steadily growing, but equipment was still unbelievably crude, weak and unreliable. Early wireless lacked two important elements, and lacking these lacked nearly everything. The first was a means of generating continuous waves of sufficient power and high enough frequency to override distance and carry continuous tonal patterns. The second was a receiver that would not merely detect these weak waves at a distance but, by some means then totally unknown, amplify them, so that reception would not be intermittent and dependent wholly on skill and chance. Without these things, wireless was still in the dark ages.

Commercial wireless stations attempted to solve the first of these difficulties by building antennas hundreds of feet high and thousands of feet long, loading as much power into the transmitter as possible, as much as 500 kilowatts of power before this early phase of development was ended. The spark-gap was the dominant transmitter of the day, but a few continuous-wave types had appeared. Chief among these was the Fessenden-type alternator and the more widely used Poulsen-arc transmitter, invented in 1903 by the Danish scientist Valdemar Poulsen, who discovered that the intense, pulsating flame generated between carbon-rod electrodes in an arc lamp gave forth continuous electromagnetic waves that might be used to transmit wireless messages. The Poulsen arc, however, was severely limited and unstable in frequency range, and it, as well as the spark-gap, lacked a satisfactory receiver. For that problem the industry had almost no solution. Some stations built elaborate sound-proof rooms for their operators in order to insure quiet for hearing the whispering signals. The signals were so weak that sunlight and static through the daylight hours were sufficient to blot them out completely, hence the industry was struggling to sell a service that was not only laboriously slow but was available for no more than half the time.

Under these technical difficulties, nearly all wireless enterprises were financially rocky, and companies rose and disappeared in record time, many being no more than stock-selling schemes. All were based on selling message services in competition with the cable telegraph, a fixation that was to retard development even as late as the early 1920's. The wireless industry regarded the amateurs attempting to experiment in this field as simple nuisances, interfering with its message business. All the early years of the century were marked by pitched battles between the two camps, recorded in many legislative halls and newspapers of the period.

From the start, Howard Armstrong identified himself with the amateurs and insurgents. He was even then working on the receiver problem with a concentration and an extraordinary expenditure of hours that were to become typical. He was also occupied in the spring of 1909 with graduating from Yonkers High School. He was nowhere near the top of his class, but graduated "with great credit" and an average of 89.8. His future course long ago had been settled. As a graduation gift from his father he received a flashing, red Indian motorcycle on which he tore about the Yonkers heights that early summer and on which he proposed to commute daily in the fall to the Columbia University School of Engineering, Department of Electrical Engineering. He chose Columbia for shrewd and practical reasons. Its School of Engineering had a high reputation, and its proximity to Yonkers would allow him to live at home and continue his attic experiments. The most inventive and teeming years of his life were now immediately before him.

Chapter 4

The Undergraduate Genius

THE YOUNG MAN who presented himself at Columbia University in 1909 for instruction in electrical engineering was going on nineteen and already over six feet tall. He had the fair hair, blue eyes and fresh complexion of a young Anglo-Saxon giant. He was still boyish, neither very handsome nor very tidy, but possessed of an abounding, attractive energy. This boyishness never wholly left him, even in later years, and it carried with it an artless quality, a native accent and enthusiasm out of that prewar period when America had not yet lost its innocence.

He slipped unobtrusively into the life of the great university. He appeared on the campus in the freshman's traditional, sky-blue beanie, wore the heavy, roll-collared sweaters favored by the college bloods of the day, and entered vigorously into the muddy pushball contest fought immemorially between freshmen and upperclassmen. He took a lively interest in sports and was to be seen, racket under arm, heading for the tennis courts on almost any clear day. Yet there was an air of serious detachment about him, which here as elsewhere quickly set him apart.

One of his early instructors remembers him in that period as a lanky, modest, retiring boy, nothing outstanding as a student, but ever inquisitive. Others on the faculty, as time went on, grew to have a different opinion. Beneath the quiet exterior was an iron purposefulness, an air of knowing exactly where he was going which to some was engaging but to others

appeared as arrogance. The curriculum was heavily weighted then toward power-station technology, the measurement and control of large amounts of electricity. But Howard Armstrong was not interested in that kind of power. He was interested in weighing grains of sand—the tiny, weak, barely perceptible currents of wireless telegraphy—rather than the fish or whales of the sea. And whatever he was not interested in, with characteristic single-mindedness, he ignored. He sauntered through the courses in electrical power, and his visible indifference was a thorn in that side of the faculty.

The class in telegraphy was a different matter. In this he was in his element. There was much chaffing and boasting then about speed in operating a telegraph key. Howard had phenominal speed. Moreover, he could thread his way through the most intricate circuits with an equally deft and lightning hand. He had read everything available on the subject, followed closely the experiments of all the leading investigators and, if challenged, could cite authorities by the hour. His instructor in the course, a slender, perceptive young man named Morton R. Arendt, who became another of his lifelong friends, quickly decided that Howard knew more about telegraphy than he did and gave him his head to pursue his own way. "There was something in him that the others did not have," Arendt said later, "and I am proud to have recognized it."

Howard's way was to putter in the laboratory at all hours, making endless measurements and experiments, reveling in all the instruments and apparatus at his disposal. It was not long before he was in trouble. Part of the trouble was that no one knew exactly what he was doing, for he had already begun to display that secretiveness that so often accompanies creation and invention. Complaints began sifting in that Armstrong was blandly violating all the laboratory rules, ignoring the set tasks and keeping no regular notebook or schedule. Some instructors were hot for disciplining him.

But Arendt came to the rescue, as he and other faculty members were to do quite frequently, staving off that urge to regiment that can be so crippling to the development of a creative mind.

From Arendt and John H. Morecroft and Henry R. Mason and Walter I. Slichter, teachers whose skill he respected, the boy from Yonkers absorbed a sense of freedom and mental voyage that was exhilarating. From them, too, he gained an insight into the immense patience and probity of science. No fact was too small to be weighed, challenged or studied. As new facts and experiences crowded in on him, he would sit down of an evening and pour out his confidences in long letters to Charlie Underhill, his Yonkers friend and first mentor in telegraphy. Underhill had been called away on a new project, hence their discussions had to be carried on by mail. These letters, written in an angular, boyish hand, crowded with technical jargon, experiments and experiences, mirror the singular absorption and high spirits of these early university years.

"For the last three weeks," he lightly begins the narrative of one episode, rising to a characteristic climax, "I have had a lot of fun with the professors of Physics at Columbia." The lecturer in physics that semester was a visiting professor from Cornell University, discoursing on high-frequency currents and resonance. The lecturer not only made misstatements of fact but, when challenged, loftily disparaged the experimental findings of others in the field, particularly Nikola Tesla, the noted inventor and a pioneer in the study of high-frequency electrical phenomena. "He even went so far as to say that there was very little originality about Tesla." Armstrong saw his chance to hit back when the visiting luminary, in the course of demonstrating spark discharges from a helical coil grounded at one end and free at the other, incautiously stated that no one could take the discharges on the

bare hand, particularly when grounded, without suffering a severe shock.

"After the lecture," Armstrong recounted with relish to Underhill, "I went up and told him I would prove that the discharge could be taken on the bare hand and could also be taken by a person who was grounded. He didn't like to be contradicted so before the associate professors and the rest of the class so he turned on the current and told me to go ahead, evidently expecting me to let go mighty quickly. I took hold of the ungrounded terminal first, thus throwing the whole system out of resonance because of the extra capacity and then took hold of the ground-wire. After the first slight shock on touching the ground I felt nothing of any consequence and could have remained in circuit all day. Everyone gave him the laugh, for he was shown up for sure. Then he wanted to try it, but he made a mistake, for he took hold of the ground-wire first and approached the ungrounded wire with his other hand. Before he got within six inches of the terminal the spark jumped to his hand. He couldn't let go of the ground-wire and he pulled most of the apparatus off the table before they turned the current off. If he got as much juice as I have taken in the same way from my own coil, I don't blame him at all for the way he acted. Two years ago I noticed how the current could be by-passed through the body by first touching the coil and then the ground-wire and mentioned it to you, but we did not reach any explanation of why the current is felt when the hand touches the ground-wire but not afterward . . ."

These were the authentic accents of a born questioner, dissenter, observer and scientist, aged nineteen, confounding the haughty doctor of the academy. He was never so happy as when he was exposing error to discover truth. Even at this early age he was impatient of the pretension which, grooved in the accepted knowledge of the day, presumed to say what could and could not be done. In another of his let-

ters to Charlie Underhill he made a long, humorous attack on instructors who cloaked all their thinking on electrical matters in long mathematical formulae, observing that this language was of no avail when, confronted by phenomena for which no formulae existed, "only plain United States could see you through." This was a theme to which he would often return. He distrusted the glibness of mathematics too far removed from physical things. With Faraday as model, he preferred to think of electricity in homely physical terms.

The young student of electrical engineering was that fearsome being, the bane of routine academic minds, a novice who thought things out for himself, not according to the textbooks, but by physical methods of his own devising. He would come up then with some awkward fact, learned in his endless puttering over electrical apparatus, which did not square with the textbooks' neat design. He had a remarkably retentive memory for the smallest details thus learned, and the time and circumstance of their learning, which he was ready to draw upon at a moment's notice. This troublesome faculty was to gain him as much enmity as passionate partisanship throughout his life. He never tired of a saying by Josh Billings which he discovered about this time and quoted evermore on the most appropriate and inappropriate occasions: "It ain't ignorance that causes all the trouble in this world; it's the things that folks know that ain't so."

In his junior year he came under the influence of a great teacher who had the ability to deal in down-to-earth terms with matters closest to his heart and interest. Professor Michael Idvorsky Pupin, a Serbian immigrant who had worked his way up in the sciences, was one of the founders of Columbia's Department of Electrical Engineering and its most distinguished personality and leading light. He was the head of the Marcellus Hartley Research Laboratory, named after its wealthy donor, devoted to the basic study of electrical

phenomena. He held forth in a room in the basement of Philosophy Hall, a room which, with its elegant walnut paneling, its early Edison lamps glowing yellowly in the gloom, its framed portraits of Faraday, Clerk-Maxwell, Ampère and other electrical greats, and its associated clutter of laboratories, was a mecca for aspiring young electrical engineers. Pupin was a product of Columbia College and had studied abroad under the noted German physicist Hermann von Helmholtz. He brought to his teaching a passion for experimental science that was in the great nineteenth century European tradition. He fought at Columbia for the idea, largely alien then to these utilitarian shores, that all teaching in the sciences should be based on the pure research laboratory and even engineers should be grounded in the fundamental sciences from which all progress came.

The dominant idea then was to grind out engineers by rote, with only the thinnest smattering of theoretical science, to staff the rapidly expanding technical industries. Research and the basic sciences, if they were considered at all, were widely regarded as fripperies, of only the remotest connection to the practical, money-making work of the world. One university trustee, opposing the expense of providing laboratories, stoutly maintained that all that was required was a blackboard and a lecturer preparing his lectures from books. "He believed," said Pupin bitingly, "what he thought would suit him best, namely, that a university should be built on the top of a heap of chalk, sponges and books." It was cheaper that way. The age was a grasping, grubbing, narrowly commercial age, fearsomely toothed, in which deep learning and the arts were tolerated merely and the only recognized success was flatly mercenary. It took strength of character to stand up against this age, and few who grew up or rose to eminence in it were wholly untouched by its prevailing values.

Pupin himself was better known as an inventor than as a

teacher of electrical theory. He was, in fact, an inventor of some renown who had earned the age's seal of approval by making a modest fortune from his inventions. These included a method of electrical tuning, widely used in telegraphy and later in radio, and the famous Pupin loading coil, a device for stepping up the electromotive force of a current, which was then a vital part of all long-distance telephony. By interposing fixed inductances at calculated intervals along a telephone line, the Pupin coils roughly doubled the range of transmission, and he had sold his invention for a goodly sum to the American Telephone & Telegraph Company. Yet he never ceased to teach and to preach that all such practical advantages could only come from the steady cultivation of knowledge in the basic sciences.

This mixture of practicality and idealism made a strong appeal to the new student who appeared in his classes one day. Pupin was a stocky, dignified man with a flashing eye, flowing moustache and gleaming pince-nez, the very picture of a doctor of science and something of a prima donna. He liked to dilate upon his inventions, tracing the first to his observations as a boy of the tuning of Serbian bag-pipes and his second to a primitive method of ground-signaling used by herdsmen in his native village—analogies more colorful than precise, and requiring a great deal of explanation. He was vain, he liked wealth and he liked to rub shoulders with the self-important of this world, whose names have been long since forgotten. But he had an original turn of mind. And to young Armstrong, then grappling with original ideas of his own, this was a quality above all to be revered. Pupin knew, in his pupil's admiring phrase, "that not everything was to be found in the books."

On his side, Pupin soon began to take notice of the tall, sandy-haired youth. It was Pupin's custom to take up the various facets of electrical theory in chronological order, describing each discovery and how it came about. He would

then wheel suddenly upon the class and demand: "By the way, who made the discovery?" Invariably, if no one else could reply, Armstrong's quiet voice supplied the answer. His reading had made him as familiar with the figures of electrical history as with his own family. To him, this history was no bloodless chronicle of abstract laws and impersonal categories but the living struggle of individual men to press back the boundaries of the unknown. Each discovery, however small, had a human habitation and a name. The pupil shared with his teacher a strongly developed sense of the individuality of scientific achievement, derived from a study of the giants whose steps still reverberated from the age immediately behind them and from other ages past. It was the beginning of a bond between them.

The association was not to become close, however, until some two years hence, when Armstrong's suddenly flowering genius brought him more forcibly to Pupin's attention. Pupin was a busy man, a member of many august scientific bodies and engineering committees and preoccupied with researches of his own. He was working then on a method of generating continuous waves to improve wireless transmission, employing a big earth-grounded electric-motor alternator for which he had received a research grant of some $20,000. Many of the leading investigators of the day were working on the same problem. Ironically, all this cumbersome apparatus was to be overturned at a stroke, much sooner than anyone knew, by the quiet young undergraduate in the class on electrical theory, who was working with only such equipment as a college student could construct for himself or borrow from his teachers.

Throughout this period Armstrong had never ceased to toil alone in his attic room in Yonkers, through long nights and weekends, methodically exploring every avenue he could conceive of that might lead to a strengthening of the wireless signal. He had, as his teachers had found, powers of reason-

ing in this department amazingly persistent in pursuit of their object. In the magical spring of 1912, this quest was moving rapidly toward a climax.

He hardly could think of anything else then, least of all meals or social graces. His sister Cricket badgered him from time to time to learn how to dance, but he never would. He was still preternaturally shy and diffident in all things except the electrical sciences. His older sister, Ethel, then beginning to attend Vassar College, brought classmates home for the holidays, but Howard would disappear upstairs into his eyrie at the first opportunity. He regarded the feminine world with a mixture of humorous gallantry and boyish detachment common in young American males of that class and period. Once he teasingly invited the Vassar visitors to ride up to the top of the 125-foot antenna mast in his bosun's chair. When one of the girls courageously agreed, he delightedly hauled her to the top. His sense of fun often flared out in the seclusion of the family, but he had no time then for the social life of college.

His energies were absorbed in the strictly masculine world of science and mechanics, sports and strenuous exercise. Evenings the attic air would still grow thick with endless talk of wireless as Bill Russell, Tom Styles and other old friends and amateurs forgathered to hash over the latest developments. The Warburton Avenue place had electricity by then and Howard, who could never get enough light on anything, had installed five big lamps in a naked row just above his work table in the big bay window overlooking the Hudson. Often these lamps blazed on unblinkingly into the pale dawn.

His life at this time moved with great concentration in a groove between the Yonkers attic and the university laboratories. He was slow to enlarge even his circle of acquaintances. Most of his Yonkers friends, including Russell, Runyon and Styles, had become members of one of those

amateur clubs that always have played a role in the history of science. This was the Junior Wireless Club Limited, organized in 1909 by a group of New York schoolboys, with Fessenden as advisor, which later was to play a large part in Armstrong's career and in the development of radio. Radio was a word that came into vogue about 1910 to distinguish continuous-wave wireless for voice transmission from the spark-gap type using code, and to be in style the boys soon changed the name of their organization to the Radio Club of America.

Almost the first action of the club was to send a knickerbockered delegation to Washington, headed by its fourteen-year-old president W. E. D. "Weddy" Stokes, Jr., to beat down the first of many attempts in Congress to have the amateur operators regulated out of existence. The newspapers carried young Stokes' resounding attack on the "wireless Trust" and his plea that "the really great inventive genius of American boys" be afforded as much protection by "this protective Government" as cotton, steel and tobacco. Armstrong followed all this with great interest, but he was not to become a member of the club until his last year at Columbia. He was not a ready joiner, he could never push himself forward and he was concentrating then with typical single-mindedness, not on the operation of an amateur station, but upon matters more basic to the wireless art.

Still he found time, as the spring of 1912 wore on, to relax with zest into his old, favorite and private pastimes. A diary of that period shows him trotting, with Cricket beside him, over to the Hudson River Country Club for a round of tennis nearly every afternoon. He also spent a good deal of time on the river. One of his friends in those years, Reginald Wand, had a fast motor boat that provided another outlet for his love of speed and driving mechanisms. Hours were spent tinkering its engine into delivering every last ounce of horsepower. Once, returning at dusk from a trip

across the river to Nyack, Cricket accompanying them, the boat ran into a sudden whipping squall on the broad Tappan Zee. They barely made it to a dock far below Warburton Avenue, late at night and long past dinner. Nevertheless, Howard was in high spirits, for danger exhilarated him, and they fell to upon sandwiches at the nearest tavern before returning home.

That summer the family moved up to Lake Bomaseen in Vermont as usual. Howard joined them later, having a field surveying trip to complete with his Columbia squad, from which there survives a neatly entered log book and a letter grumbling at the weariness of pacing lines through a swamp. He spent a good deal of his time in Vermont that summer slipping off alone to climb some of the roughest mountains in the vicinity. On one of these expeditions some time in August, while thinking over the problems never far from his mind, he was struck by an idea. Suddenly all the charms of Vermont faded and vanished. He was suddenly and feverishly impatient to get back to Yonkers and his wireless apparatus.

When in the normal course of events he did get back to Warburton Avenue early in September, it was only to be met by another delay in putting his idea to the test. A storm earlier in the summer had wrecked part of his antenna mast and repairs were needed to get it back in working order. It was September 22, therefore, before he was able to begin a series of experiments which, from the moment he completed the first hook-up, unfolded a new principle that was to have the most profound and far-reaching effects of any idea since Marconi's discovery in the top story of his parents' villa near Rome in 1895 of the earth-grounding principle by which wireless waves could be sent over the world.

At Columbia University that fall, with his senior year still before him, Howard could barely contain his mounting excitement and preoccupation behind his usual bland man-

ner. The further he extended his experiments, the more certain he was that he had made a discovery for which some of the world's best investigators were searching. He cannily kept it to himself. He housed his apparatus in a mysterious box, which soon became a familiar appendage as he carted it back and forth to the laboratories for tests and measurements of greater length than ever before. As the winter wore on, he told one of his closest classmates, Herman Burgi, Jr., that he had discovered some new circuits, unspecified, for greatly amplifying wireless signals. He demonstrated the startlingly loud reception of distant signals to his Yonkers cronies, but did not trust even them with an explanation of how the effect was achieved. He dropped hints of what he was about to his favorite instructors, who, though they had no idea of the range of his discovery, advised him to seek a patent.

This promptly precipitated the first major crisis of his life, for the cost of filing for a patent then came to about $150, and John Armstrong, fearing that all this was diverting Howard from the main business of securing a university degree, flatly refused him the sum until he graduated. No doubt his father did what he thought best, and he may well have been skeptical of the importance of the invention, for to the layman's ear, and even to the ears of some professionals, the loud squeals, beeps and howls that came from the marvelous apparatus, with nothing except telegraph stations to tune in on, sounded like anything but a great discovery. To Howard, however, the refusal was a crushing rejection.

It was then January of 1913 and every moment counted. Until a patent application was filed, the great secret would have to remain bottled up within him, and there was always the danger that someone else, by hint or chance, would leap in to establish a priority before him. Howard began a frantic canvas of friends, relatives and resources, trying to raise the $150. He sold his motorcycle, but the sum he could get

for it was not nearly enough. He was at the end of his tether when he approached his uncle, Frank Smith, who, being just married, was forced to refuse him, but suggested, from some background of legal knowledge, that he get up a sketch of his device and have it witnessed and notarized. This would pin down the date and priority of his conception until such time as he could file for a patent.

Howard was eternally grateful for this advice, for until then he had not known which way to turn and had met with only a wall of incomprehension. He hastily drew up a diagram of his circuit, which theretofore he had been afraid to trust to paper, and on his way to school one morning, with Herman Burgi as witness, he dropped into a small real estate office on Lenox Avenue near 123rd Street in New York to have it notarized. The notary perfunctorily affixed his seal and signature for a fee of twenty-five cents. The date was January 31, 1913, a date vital in subsequent history. With this document, the first of Howard Armstrong's inventions was officially, if still only privately, launched upon the world.

Chapter 5

The Inventive Act

IT MAY BE well at this point to inquire into the basic nature of invention and inventors. In the common view there has never been much ambiguity in the term. The great *Oxford English Dictionary,* based on historical principles, is admirably to the point. An inventor is "the first finder-out." But this common-sense view has been so obscured by the multiplicity of modern developments and the confusion of conflicting interests that many spurious ideas are afloat as to how inventions are made and who brings them about.

One such notion, favored by pedants of pure science, is that true invention is no longer possible, for everything new is traceable back through previous discoveries to the ancient Greeks, who, in one way or another, thought of nearly everything. Another notion, favored by corporations, is that invention has grown so diffuse that something new can rarely be credited to a single man but rather to the organizing genius of modern corporations. Still another is that inventions spontaneously arise out of the economic and social necessities of the time, without regard to individuals, as witness the frequency with which the same discovery is made almost simultaneously in different parts of the world by different men. The ultimate expression of this notion is that inventions may be ordered or made by a commission, a corporation, a team or an expenditure of a million dollars.

All these notions are alike in that they would dilute, where they cannot wholly suppress, the genius of the individual, the

only instrument capable of making inventions. This is the old attempt, supported by modern force and control of mass communications, to be rid of the troublesome intervention of genius. For genius, in the end, cannot be bought, nor can the mysterious workings of its mind be ordered. Invention shares with art the intransigence of the creative process. And great inventions are made, not by ordinary, tame, conforming men or any association of these in whatever number, but by minds capable of original thought, of which there are few in any generation.

It is true that all invention works upon a body of accumulated knowledge, so that each invention has a lineage linking it with discoveries in the past. It also is true that the level of knowledge and pressure of social forces at any given moment make certain inventions possible, so that occasionally two or three workers may approach the same invention almost simultaneously. But the moment may well be lost and the invention forced to wait upon the right man to conceive it. The man who first joins the disparate discoveries of the past into something entirely new, with demonstrably new effects upon the real world, is the inventor. By hindsight, the invention then appears to have been inevitable, and it is upon this appearance that small men trade, suggesting that if one man had not made the discovery others would, possibly themselves, if they had had the time, luck or opportunity.

But there is nothing inevitable about a great invention, as the long, jagged history of science, with its missed opportunities, zig-zag progress and puzzling delays, often extending into years and decades, amply demonstrates. No better illustration is to be found than in the long, hard-won history of electrical science and in the incredible series of fumbles and mischances leading up to 1912, when an undergraduate schoolboy, barely past his majority, snatched from under the

noses of some of the world's most eminent investigators one of the decisive inventions of this century.

The story begins, as might be expected, with the Greeks, who made one of the first recorded observations of electricity by noting that amber, when rubbed, displayed a mysterious force that drew light objects to it. The Greek word for amber was *elektron*. But Greek thought, and that which followed for centuries thereafter, had the static flaw of divorcing knowledge from purposeful action or investigation. The mysterious force in amber did not begin to be understood until the seventeenth and eighteenth centuries when, with the real dawn of experimental science, men began to study electrical phenomena at first hand by means of ingenious friction machines, magnets and Leyden-jar condensers, invented about 1740 by the celebrated Professor Pieter van Musschenbroek of the University of Leyden, Holland.

Not until the opening of the nineteenth century did the mysterious flow of energy from Leyden jars and thunder clouds begin to be defined, measured and codified by such experimentalists as André Marie Ampère of France and Georg Simon Ohm of Germany. And it was well into the century before Michael Faraday, in a series of experiments that changed the world, showed how men might produce electricity by a more reliable means than rubbing amber or rotating glass balls in friction machines. In 1831, after nearly ten years of pondering and failure, he performed his classically simple experiments in electrical induction. A bar magnet passed through a coil of wire induced a flow of electrical current in the coil, thus indicating that magnetism might be converted through motion into a continuous source of electricity. But it was another half-century before the rotary apparatus and circuit techniques were developed to translate this principle into the first electrical dynamos. And a pitched battle then ensued between industrial interests, particularly in America, over the relative merits of direct versus alternat-

ing current, delaying by nearly another quarter of a century the widespread extension of electric power.

These two types of electrical current appeared in the development of Faraday's basic discoveries. When induction coils wrapped on an iron-core armature and shaft were made to rotate between fixed magnets in the earliest form of dynamo, the current produced was a fluctuating one, changing direction as the coils approached and receded from the magnetic poles. This was alternating current, and at the low rotational speed of early dynamos it produced a visible flickering in electric lamps and unsteady drive in industrial machinery. By arranging the withdrawal of current so that each side of the rotating coil was tapped in turn as it approached the magnetic poles, a steady continuous current was produced. This was direct current, and its immediate usefulness channeled nearly all early investment into direct-current generators. Direct current was conceived as electricity moving in only one direction, like water through a pipe; alternating current as electricity moving rapidly back and forth, up and down, like wavelets in a brook.

It soon developed, however, that if alternating current were speeded up to many cycles or waves per second, it gave the effect of a steady current, with some marked advantanges over direct current. The apparatus to effect this was developed about 1885 by Lucien Gaulard and John Nixon Gibbs in Europe and by George Westinghouse and William Stanley in the U.S. Direct current had the inherent defect of being difficult to distribute over wide areas. To transport electricity for long distances over wires, it must be transmitted at high voltages to overcome wire losses. And at these voltages direct current required expensive motors and generators at each point of use to step the voltage down to safe levels. But alternating current was not only easily generated and transmitted at very high voltages, it was also easily stepped down at point of use by simple transformers (also discovered

by Faraday), allowing a much more flexible, economic system of distribution from central power stations. Yet until well past 1900 alternating current was bitterly fought and blocked in its growth by financial interests.

Nearly all electrical thinking in this first phase of development was confined to wires. In 1844 Morse showed how electrical impulses over wires could be made to carry coded signals at a distance in the first practical system of telegraphy. In 1876 Bell showed how these impulses, made to vibrate diaphragms, could carry the human voice via telephone. But Faraday, whose seminal discoveries had made all this possible, foresaw much else. He suggested that there was an underlying unity in all natural forces or forms of energy and that the magnetic "lines of force" which he conceived as moving invisibly out from all electrical conductors might hold a clue to another, freer form of radiant energy. As early as 1832 he wrote: "I am inclined to compare the diffusion of magnetic forces from a magnetic pole to the vibrations upon the surface of disturbed water, or those of air in the phenomena of sound, i.e., I am inclined to think the vibratory theory will apply to these phenomena as it does to sound, and most probably to light."

Thirty-two years later, in 1864, the unity of electrical phenomena was revealed with great mathematical force by the English experimental physicist James Clerk-Maxwell in his epochal *Dynamical Theory of the Electrodynamic Field.* At the center of this theory was the proposition that electricity or electromagnetic force was part of a continuous spectrum of energies, including heat and light, which could be converted one into the other and which were alike in that all took the form of vibratory wave phenomena, being distinguishable only by different wavelengths. If this were so, then electricity need not be confined to wires, but might be manipulated freely, like light, through space.

The Clerk-Maxwell theory was a mathematical theory and

difficult to penetrate. Some twenty years elapsed before Heinrich Rudolf Hertz, a brilliant young assistant to Von Helmholtz at the University of Berlin, set out, at the suggestion of his master, to try to confirm it. Some time was needed merely to see through the mathematics to some physical way in which to test it. It was 1887, therefore, before Hertz showed, in another classically simple experiment, that electrical waves could, indeed, be propagated through space like light. His apparatus consisted simply of two metal spheres separated by a short gap across which electrical sparks were made to leap back and forth or oscillate. At the other side of the room, unconnected with this, was an open copper-wire loop of carefully calculated dimensions. When the spheres sparked, the unconnected loop sparked rhythmically in resonance with them, indicating that invisible waves were being sent out from the spark-gap and detected by the loop. These waves proved by their nature to be high-frequency waves of alternating electricity. They could be measured, focused, reflected and refracted like light, but, being of a much longer wavelength than light, they passed invisibly through objects, walls and other matter, presumably straight out into space. Hertz died at the early age of thirty-seven before he could investigate further.

The germ of all wireless telegraphy and radio was contained in Hertz' rudimentary apparatus. The spark-gap served as the first sending station or transmitter, sending out a train of electromagnetic waves into space. These were impalpable but very real waves of electrical energy with a specific frequency or wavelength, measured from crest to crest. They could be made to carry the short and long impulses of telegraphic code and, later, the sound-wave pattern of human speech, just as current along a wire carried ordinary telegraph and telephone messages. Hertz' simple copper-wire loop was the first wireless detector, receiver and tuner, rolled up in one. Its dimensions were nicely calculated to receive

and tune-in the specific wavelength being sent out, vibrating to that wavelength much as a tuning fork responds at a distance to the wavelength of a note struck on a piano. (Audible sound is a low-frequency wave phenomenon in the range of 30 to 20,000 cycles or waves per minute, whereas radio waves vibrate in the range of hundreds of thousands to millions of cycles per second.) This tuning principle was later developed by Sir Oliver Lodge into a variable tuning coil with many loops to allow the selective tuning-in of stations operating on different wavelengths.

Marconi's great achievement was to take Hertz' crude apparatus and the Hertzian waves and, little more than a decade after their discovery, hurl them far out into space. To do this he greatly increased the power of the Hertz spark-gap transmitter and devised a high, earth-grounded antenna to send out waves for long distances over the earth. He did this in the face of massed scientific opinion which held that such waves could not be picked up at any great distance because, traveling in a straight line, they must go off the earth at the horizon. Marconi's feat was to show that by earth-grounding the transmitter the waves could be bent to follow the curvature of the earth and thus open a new era in world communications. This was the discovery of the so-called groundwave, for which Marconi later received the Nobel Prize in physics. The waves went out from the transmitter with the speed of light. As they rippled out, retaining their form for hundreds and thousands of miles, they rapidly diminished in power. Hertz' wire-loop receiver was of no use here, for it only worked at a distance of a few yards. The problem of finding a receiving device that would do more than simply detect the weak, attenuated waves at long distances hobbled the development of wireless telegraphy, as we have seen, for the next decade or more.

Many devices were tried, none of which did more than feebly detect signals at a distance. Marconi's first receiver

was of the coherer type noted earlier—a tube of metal filings that cohered and passed a weak current when struck by a high-frequency wave, invented by Lodge in 1894—but it had a range of only 100 or 200 miles. Later he developed a more sensitive magnetic detector of his own, which worked over longer distances and dominated most of the early days of wireless. After 1900, two new devices came into play, mainly among experimenters and amateurs, who found them somewhat better and more promising in performance than the magnetic type. The first and most widely used of these was the crystal detector—the crystal-and-cat's-whisker receiver of revered memory—invented about 1906 by two almost forgotten Americans named H. H. Dunwoody and G. W. Pickard. This consisted of a single crystal of quartz or galena with a fine wire contacting its surface, which had the mysterious ability, when connected in circuit to an antenna, of detecting and passing on as direct current the high-frequency alternating waves from the air. The second device was the first crude forerunner of the modern vacuum tube, whose principle was discovered in 1883 but which saw little development or use until 1912.

The vacuum tube presents one of the longest and most tortuous episodes in the history of invention. Its principle was discovered by Edison in 1883 in the course of investigating a troublesome defect in his early carbon-filament electric lamps. At high voltages, carbon particles were rapidly carried off the glowing filament by some means and deposited as a black film on the inside of the bulb, causing the lamp to burn out. Edison suspected that some unknown electrical force was at work and devised an experiment to find out. Inside the lamp he suspended a tiny metal plate, connected by a wire lead to a battery outside the lamp. When the lamp was hooked up to this battery in a certain way (the plate to the positive terminal of the battery, the filament to the negative), a galvanometer registered the fact that a tiny current

was flowing across the empty gap from the hot filament to the metal plate. When the lamp was hooked up in the opposite way (plate to negative terminal of battery, filament to positive), no current flowed. This indicated that the lamp's tiny filament-to-plate circuit passed current in only one direction (i.e., direct current) and was in effect a rectifier of alternating current to direct current.

Edison puzzled over this for some time and even patented it, for it was something entirely new. But he could not explain it and he did not have the analytical mind to investigate such obscure phenomena. Edison was of the older, empirical school of inventors, only a few steps removed from the Yankee tinker, skimming prolifically over the surface of the known for patentable new products and moving rapidly by trial and error from one field to another. In 1875 he had passed over a sparking phenomenon in a circuit on which he was working—duly noted in his voluminous notebooks but never followed up—which was later seen to be in essence the Hertzian-wave transmitter. Again in 1883, he failed to see anything of immediate significance or use in the tiny electrical effect noted in his incandescent lamp. For lack of insight, the "Edison effect," as it came to be called, remained merely a curious observation for the next twenty years.

The second act of the drama occurred in London in 1904. There a professor at University College, named J. Ambrose Fleming, suddenly applied the Edison device to the detection of wireless signals. Fleming's part in the invention was almost as curious and stumbling as Edison's own. An itinerant teacher of science in English schools, who had studied briefly under the great Clerk-Maxwell at Cambridge, Fleming was employed for a time around 1882 as a consultant to the Edison Electric Light Company of London, when he became acqainted with the "Edison effect." After considerable research on it, which lead nowhere, he put it aside. About 1900 Fleming became consultant to the Marconi Wireless Telegraph

Company to help design the new transmitter at Poldhu with which Marconi proposed to span the Atlantic. At the same time he was drawn into the pressing search for a more sensitive detector. Only after some two years of fruitless research did he happen to remember his experiments with the Edison lamps of twenty years before. He took the dusty bulbs from a cabinet, set up a spark-gap generator, and at once discovered that the filament-plate device, hooked into a receiving circuit, responded by passing a current when struck by the high-frequency waves.

Fleming improved on Edison's filament-plate arrangement for wireless use and secured a patent on it which became the property of the Marconi Company. He called the device a valve, because it passed a current in only one direction. But it was still essentially Edison's old incandescent lamp device. And when applied to wireless, it proved no more effective than other detectors before it. This was because it was, in fact, a simple valve of only two elements—filament and plate—with nothing to modify the current flowing between them in any way. It operated on the same basic principle as the crystal detector and other receivers of the day; i.e., it simply detected and converted the high-frequency alternations from the air into direct current to actuate a headphone. At whatever strength the signals came into such a receiver, they were passed on much as they were found. For some reason, Fleming never tried any measures that might have suggested themselves for strengthening or controlling the current within his device and went no further with its development. Fleming valves were manufactured in some quantity, for they were highly interesting to researchers, but they never entered widely or decisively into wireless.

The scene then shifted rapidly back to the U.S., where, in 1906, the American Lee de Forest did what Fleming failed to do. He added a third element between filament and plate, consisting of a perforated metal or wire grid, which, when a

slight charge was imposed on it, controlled or modified the tiny current flowing across the gap. De Forest, of whom much more will be heard later, was then thirty-three. He had been born at Council Bluffs, Iowa, the son of a Congregational minister, educated at Yale University's Sheffield Scientific School, and immersed since graduation in the inventive field. A stocky, black-haired, energetic man with a hard-clipped moustache, he was an inventor of the Edison type, mixing invention with commerce. He was then struggling to build up a mass of patents in the wireless and telephone field, at the same time that he was trying to promote the American De Forest Wireless Telegraph Company, both of which activities were in legal and financial difficulties. He had seen the missing element in Fleming's work and quickly stepped in to secure a patent on it.

But de Forest's audion tube, as he called his device, proved hardly more sensitive, when inserted in a receiving circuit in the usual way, than the Fleming valve and other detectors before it. It slightly strengthened the signal, but by what means no one then knew. De Forest, like Edison, lacked the analytical mind to investigate and explain the tube's operation, now greatly complicated by the addition of the third or grid element. Moreover, de Forest at this time was being pushed out of his wireless company and was scrabbling for another foothold. Early in 1912 he attempted to develop the little-used audion as a repeater or relay device on long-distance telephone lines. When tuned into a circuit, however, the tube emitted a howling tone that made it useless for telephone purposes. De Forest tried to get rid of the howl, and therewith passed over another important phenomenon. Six years after its introduction, the audion was almost nowhere to be found in regular wireless operations. A few tubes were sold at $5 apiece to avid amateurs, but the audion was regarded simply as another detector, too difficult of adjustment to be much bothered with.

It may be questioned whether, up to this point, anyone had made a full-scale invention. De Forest had made an important addition to the Fleming valve, which Fleming had adapted straight from Edison's lamp-filament-and-plate device. Each had contributed an essential part to the whole, but none had successfully shown how it might be used to do anything that had not been done before. If original invention was to be credited to anyone, it was to Edison, for the whole principle of the tube was contained in the "Edison effect"—the flow of current across a sensitive gap between cathode and anode in an evacuated tube. Yet this was more in the nature of a basic discovery than a useful invention in itself. In fact, among the thousand or more inventions that Edison patented in his lifetime, the "Edison effect" is now recognized as his only original scientific discovery.

It was into this stalemate that young Howard Armstrong stepped in 1912 and, through a searching analysis of operations within the audion, devised an entirely new circuit in which its amazing powers were released. Armstrong had run through all the stages from coherer to magnetic detector to crystal rectifier to Fleming valve, quickly concluding that none of these offered any means of augmenting weak signals. Early in 1911 he had bent his attention to the three-element vacuum tube, whose puzzling operation then intrigued many investigators. His first pair of tubes was given to him by Charlie Underhill, who thus put him on the road to his first invention. The more Armstrong observed the tube as a detector, the less satisfied was he with explanations of how it worked.

In the detector circuits in which it was used, the audion was generally hooked up in the following manner. The tiny grid was connected in a tuned circuit to the receiving aerial, while the plate was connected in a straight telephone circuit with a battery to the headphones, both circuits being joined to connect with the hot filament. De Forest and others ex-

plained the action of the tube as a controlled flow of gaseous ions or charged gas particles, supposedly created in the space around the hot filament and carrying the current across the gap from filament to plate. This fanciful explanation lacked any relation to current knowledge in physics. The English physicist O. W. Richardson had shown, purely experimentally in 1903, that hot filaments or conductors in an evacuated tube threw off from the metal itself tiny, invisible charged particles called electrons, the smallest negatively charged particles of matter, discovered by Sir J. J. Thomson in 1897. Physicists were just beginning to see that all electrical currents are simply a flow of electrons along wires or through space. But these concepts had not yet penetrated very far into wireless engineering.

De Forest offered various explanations of how the audion tube operated in the usual receiving circuits of the day, all of them erroneous and all preserved in the literature down to 1915. The rapidly alternating waves from the air were led down from the aerial through a tuned circuit to the tiny metal grid in the tube, interposed between the tube's filament and plate. The grid, rapidly alternating from positive to negative in response to these waves, in some way controlled or modified the tiny "Edison effect" current flowing steadily from the hot filament to the plate and to the headphones. De Forest, who held that this current was composed of gaseous ions, maintained that the positive and negative charges on the grid acted "either to repel from its neighborhood the ionic carriers or to hold them idle there." Either way, the crucial action of the grid was to diminish to a greater or lesser extent the current to the plate and headphones. Later he described the grid's action as a trigger action. These erroneous theories blocked the way to an understanding of how the tube's plate current or output might be increased.

Armstrong, always ready to question the accepted order of things, suspected that there was something wrong with the

theories. No one had bothered to make a careful study of the charges on the grid to find out exactly what their effects were on the plate current. Thrusting all theory aside, therefore, he set about making an exhaustive analysis of currents and voltages in the audion's circuit with the aid of Professor Morecroft and the school's laboratory oscillograph. From these studies he came up with the discovery early in 1912 that some alternating current was being produced in the plate current—where, according to theory, no alternating current should be, but only a diminished direct current. This small observation provided a vital clue. It was common practice in electrical engineering to augment or step up an alternating current by tuning. What would happen if, in addition to tuning the antenna-to-grid circuit, he placed a second tuning coil in the plate-to-headphone or output circuit—commonly called the "wing" circuit at that time—and then tuned this output back into the grid circuit? This was the big idea that struck him in Vermont that summer. The stages leading up to it and the astounding results were laconically set down by him in a note some time after the event:

"1. In either 1909 or 1910 first used two-element audion or Fleming valve.

"2. In beginning of 1911 first used the 'grid' audion.

"3. Experimented with a number of bulbs and read up on various explanations which had been published concerning its action. Found them all unsatisfactory and started to think about it.

"4. August 1912 speculated on effect of tuning 'wing circuit' of an audion.

"5. Repaired antenna, which had been wrecked by storm in July, during first part of September.

"6. Sept. 22, 1912 set up circuits and tuned 'wing circuit.' Great amplification obtained at once. Noticed peculiar change in tone of signal just as maximum amplification was

obtained. Signals changed from clear to hissing note and audion also hissed when wing inductance was set at certain value."

As Armstrong investigated the new phenomenon in various circuit arrangements through the winter of 1912-1913, the results continued to be astounding. Distant signals, which had come in before only as a whisper on the most favorable occasions, came in so loud that the headphones could be left on the table and the message distinguished across the room, a thing unheard of. Nearby amateur stations, which had never had enough power to get from New York to Yonkers, came in with such volume as to "paralyze" the tube. With only a single audion and such apparatus as might have filled three or four shoeboxes, he regularly heard Glace Bay, Nova Scotia, Clifden, Ireland, and other stations over Europe. The apparatus pulled in not only spark signals but also continuous-wave signals from Poulsen-arc stations all the way from Sayville, Long Island, where German Telefunken had a station, to San Francisco and Honolulu. No commercial apparatus then known had such range or power of amplification.

When Armstrong tuned the "wing" circuit of his audion back into the grid he uncovered a new principle in wireless communications of the most far-reaching consequences. The effect of his action was to feed back part of the audion's plate or output current to its grid or input current. Thereupon the original incoming signal from antenna to grid was boosted in power, producing an increase in current to the plate. This happened over and over again, in the lightning-like movement of electronic currents, building up the plate current to unheard of heights. Contrary to accepted theory, every increase in positive charge on the grid increased the flow of current from filament to plate. Thus a greatly magnified copy of the signals coming in on the grid was im-

pressed on the plate current and in turn on the headphones, amplifying the original signal as much as a thousand times. This was the principle of feedback or regenerative amplification.

When, however, the audion reached its highest amplification, it developed, as Armstrong quickly noted, a hissing tone. Under certain conditions, repeated at will, the hiss rose to a whistle, then to a howl. To secure proper reception, regeneration had to be limited to a point just below this critical stage. Never one to ignore any curious noises in his apparatus, Armstrong began to investigate the hissing tone, coming to the conclusion, as he detected beats in the tone, that the tube was putting forth oscillations of its own. This was the howling phenomenon that de Forest had passed over that same year. Instead of trying to eliminate the howl, however, Armstrong recognized it as an integral part of the operation of the tube, to be studied and controlled. Shortly afterward he proved that the audion was, in addition to being a receiver, an oscillator of electromagnetic waves. Beyond a certain stage of amplification, with certain changes in the circuit, the audion became a modified Hertzian oscillator and powerful generator of high-frequency waves.

Thus was discovered in one small instrument not only the improved receiver for which the wireless age had been searching, but also, and what was least expected, the transmitter which would make sustained and reliable radio broadcasting possible. The feedback principle from which this flowed was not unknown to engineering. Engineers had applied it in the governor on steam engines and in even more ancient arts. It had even been suggested in wireless telegraphy by others before this. But none had found a way to make it work until Armstrong welded the hints, discoveries and elements of the past into a new instrument that marked the real end of the dark ages in wireless telegraphy. Armstrong at twenty-two—exactly the same age at which Marconi had made his first dis-

covery—had brought off one of the greatest achievements in the wireless art.

It has been said that the power of great invention is the power to hold a problem in the mind for days, weeks and even years until the problem is seen straight through. This muscular grip of the mind is more rare than anyone might suppose. Potentially, the vacuum tube could have been invented and developed almost concurrently with the early development of wireless, for its principle was discovered in 1883, five full years before the discovery of Hertzian waves. None of the early minds that came to grapple with it, however, had the staying power. It was thirty years, therefore, before the vacuum tube was made to yield its secret. Armstrong's role in the invention was the dogged, probing mind to see it through. In this as in his later inventions he was the great prose master of electronics, putting together the words and phrases of electronic circuitry until they took on magical new forms and meanings for the world.

Chapter 6

"Feedback" Armstrong

IN JANUARY of 1913, however, Howard Armstrong was not a recognized inventor but an obscure undergraduate with his last semester in electrical engineering still before him. To get his degree and get out was then a paramount aim in his life, for until he did so, his father adamantly assured him, there would be no money forthcoming for patenting his invention and getting on with its development. He applied himself with a will. But in his wireless invention he had a bear by the tail, of extraordinary proportions, that made everything else tame by comparison and dominated his life henceforward.

The regenerative or feedback principle was a concept of such subtlety, all taking place within the minute currents of the vacuum tube, that its full implications could hardly be taken in at a glance. Armstrong could not rest until he understood it, through experiment after experiment, in all its properties and manifestations. In particular, there was that hissing tone to be investigated—a most curious thing. In December of the previous year he had noticed that in the hissing state the audion, when tuned to continuous-wave stations, gave off peculiar whistling noises in which he detected a distinct pulse or beat. During January and February he continued to hear whistles of varying pitch and whenever his hand approached close to the apparatus he observed that the tone changed. He suspected that the tube was internally oscillating; i.e., sending out radio waves of its own.

Altogether it took him nearly six months to get to the bottom of this, with the aid of meters and other instruments borrowed from Henry Mason, one of the professors with whom he was then most intimate. The fact that this discovery came nearly six months after his original invention of the regenerative circuit set up a curious hiatus in Armstrong's mind that was to cause him untold trouble in years to come. Instead of regarding both the receiving and transmitting functions of the audion tube as aspects of the same invention —regeneration—he regarded them as separate inventions. Moreover, the receiver problem had absorbed his attention for so long that it took precedence in his mind over this unexpected solution to the transmitter problem. Yet the audion as transmitter was destined to be regarded as the greatest aspect of his invention, for, while the regenerative circuit was to be replaced shortly in receivers by improved circuits of his own devising, it has not yet been displaced from its role as the primary generator of electromagnetic waves.

Certain traits in Armstrong's character contributed to this lapse in judgment. He was secretive and stubborn in the direction of his own affairs. He would listen to advice, but go his own way, keeping his own counsel. He was sagacious beyond his years, but he could not foresee all the pitfalls ahead. Perhaps the most serious fault, flowing from all this, was that he would never keep a regular or orderly laboratory notebook, describing his experiments as he made them, preferring to keep everything in his head until he was ready to make a full disclosure to the world. These traits persisted and were so inextricably woven into his inventive nature as to have the look of fate about them.

Meanwhile, late in March, 1913, he persuaded Henry Mason to come up to Yonkers one evening for a demonstration. He had discussed the oscillating phenomenon with Mason and showed him the notarized sketch of his circuit. The two became so absorbed in pulling in distant signals,

however, that when Howard got around to setting up a second audion to show its oscillating characteristics there was only five minutes left for Mason to catch the last train back to New York. Late in the spring, when he had worked out a reliable method for receiving continuous-wave stations, he had Arendt up for an exciting evening. San Francisco came in clear as a bell, then Pensacola, Florida, not only direct but as its signal was relayed up the coast from Navy station to station as far north as Arlington, Virginia. Nothing like it had ever been heard before. Later Arendt suggested that he use the oscillating feature for a transmitter, but Howard replied cryptically that he was only interested in receivers. That same spring he delivered his first technical paper, a general paper on the theory of tuned circuits, before the Radio Club of America, which had grown so that its meetings were then being shifted to a lecture hall at Columbia.

How Armstrong managed to graduate in addition to all this is something of a mystery, but graduate he did in June of 1913 with his prized degree in electrical engineering. It was touch and go for a time, some of the old resentments of a part of the faculty rising to plague him, but high merit marks from others who knew of his work pulled him through. Their kindly intervention did not end there. Upon graduation, Howard was offered an appointment as assistant in the department for one year at a salary of $600 a year, payable monthly, which he quickly accepted. Arendt and Walter Schlicter, head of the department, had got busy and found a class in Navy wireless in need of an instructor, knowing that Howard would be more or less at loose ends and still in need of a laboratory to continue his investigations. John Armstrong, who promptly made good on his promise of patent money, was prouder of this teaching appointment than of almost anything else. "Buzz," he wrote to his daughter at Vassar, "is to have his name posted on a door—E. H. Armstrong, Instructor—think of that! They call him a wizard."

Arendt advised Howard on patent procedure and wrote a letter introducing him to a prominent patent attorney named William H. Davis, member of the firm of Pennie, Davis, Marvin and Edmonds. Howard went downtown to see him. Davis, who had done much patent work in the electrical field, was quick to recognize that the young man had something important. He told him not to worry about money but to file for a patent as soon as possible. Summer intervened, however, and the task of getting up a clear description of his invention took more time than anticipated. It was late fall —October 29, 1913, to be precise—before the application was filed, and then it was for "new and useful improvements in wireless *receiving* systems." Howard had refrained from mentioning the transmitter features of the feedback circuit to Davis, which was something like withholding information from one's doctor and almost as fatal in its results.

When Howard sent Davis a check for $124 to cover the filing fee and legal services, he got back a prompt reply that in the light of subsequent events took on the sharpest significance. "You are certainly getting astounding results," wrote Davis, "and it seems to me that the invention ought to be worth a lot of money. I feel great responsibility in connection with the patent end of the invention, and think you ought to keep your eyes wide open to see any indication that may point to the importance of features other than those covered in your application."

There was still time to amend or broaden the application to include the oscillating features, but Howard had it fixed in his mind that this was a separate invention on which he would file for a separate patent. And, in fact, it was only a few weeks later that he was instructing Davis to file for a second patent on the transmitter aspects of the feedback circuit, the application being dated December 18, 1913. Since the audion as transmitter required somewhat different circuits, many of which were yet to be developed and all of

which remained to be proved in service, it was, perhaps, a natural mistake. Through this crevice, however, was to come litigation making hideous the whole first quarter-century of radio development.

Nothing of this yet disturbed the fall and winter of 1913-1914, which was filled for Armstrong with the mounting excitement of investigation, discovery and the unfolding of new principles to the world. While teaching Navy officers the rudiments of wireless and marking endless student papers, he pursued his studies of regeneration. Early in the semester he had explained the operation of the regenerative receiver to Professor Pupin and demonstrated the reception of arc-station signals to Professor Morecroft. Pupin, with typical warmth and magnanimity, at once hailed the discovery as of epochal significance and began to take Howard under his wing. Howard strung up an enormous aerial on the campus between Schermerhorn, Havemeyer and Philosophy Hall, and one evening, while Pupin was about, got Honolulu direct so clear and strong that the old man was in raptures. Pupin had many connections in the business world and rhapsodically spread word of this new marvel. From this and from other sources a series of historic meetings took place that winter that were to be like stones dropped on the surface of a still pool.

In December a demonstration was set up in Pupin's laboratory for a group from the Marconi Wireless Telegraph Company of America, subsidiary of the British Marconi Company, which was then trying to dominate wireless over the world. In the group was a young, dynamic assistant chief engineer named David Sarnoff, who was to play a leading role in the unfolding of Armstrong's inventions and in the drama of his life. Born in Minsk, Russia, and brought to the U.S. at the age of nine, Sarnoff had started as an office boy with the American Marconi Company, studied wireless at night school, put in shifts as a wireless operator at sea, and scram-

bled up through various operating and commercial divisions of the company to his present position, from which he was to go on rising rapidly higher. Few men of equal age could have been more diametrically opposite in background or character: Armstrong tall, slow-spoken, extremely reserved, the analytical mind; Sarnoff short, fluent, aggressive, the entrepreneur. Yet they hit it off, for Sarnoff could see even then, more shrewdly than his older associates, some of the stunning commercial implications of this powerful amplification of wireless signals.

The demonstration went off smoothly. Armstrong, who had concealed his apparatus in a stout box, performed the feat of bringing in with unprecedented clarity signals from British Marconi's own transmitter at Clifden, Ireland. Sarnoff copied the messages and a few days later had them verified by the British company. This was so impressive a feat that Armstrong was asked to set up his apparatus for more extensive tests at a new station the company was building at Belmar, New Jersey. There in a drafty wireless shack one bitterly cold night in January, 1914, Armstrong and Sarnoff sat through the night copying messages from Clifden, Ireland, Poldhu, Cornwall, Nauen, Germany, numerous arc stations on the West Coast and finally signals from Honolulu, coming in with great strength in the early morning hours. All these messages were checked with the originating stations, confirming the fact that this new circuit, still undisclosed, was a revolutionary amplifier of signals so weak that they rarely, if ever, had been pulled in from such distances before. Thus the first full-scale test of the regenerative circuit went off with astonishing success, yet it was not until more than a year later that Armstrong again heard from American Marconi.

Meanwhile, Pupin had boasted of hearing Honolulu direct before a group at the University Club in New York, including the openly skeptical chief engineer, J. J. Carty, of the American Telephone & Telegraph Company. A demonstra-

tion was therefore arranged early in February, 1914, for an august body of A.T. & T. engineers. They listened with reserve, copying down signals that were later confirmed. Part of the reserve may have been simple chagrin, for A.T. & T.'s research laboratories, among the earliest and best in American industry, had been working all around the discovery without making it. In 1912 de Forest had demonstrated his audion telephone-line repeater to them, leaving his apparatus for the engineers to study, and late in 1913 A.T. & T. had acquired from de Forest exclusive wire and telephone rights on the audion for $50,000. Since 1912, therefore, A.T. & T. had done intensive work on the vacuum tube. In the summer of 1912, however, still another inventor, Fritz Lowenstein, had discovered how to make an audion amplify in a telephone circuit without howling. Now an unknown young man, barely out of school, was demonstrating an even more revolutionary effect. Later in the spring of 1914, Armstrong disclosed the workings of his feedback circuit to A.T. & T., but, for reasons that will soon appear, he did not hear from the company again.

Perhaps the most dramatic meeting of this period occurred in the fall of 1913 when Lee de Forest addressed a session of the new Institute of Radio Engineers, formed just the year before, on the subject of the audion amplifier, using the telephone-repeater circuit he had been demonstrating to the telephone company. The lecture was held at Columbia. This was Armstrong's first meeting with the inventor of the three-element audion, and the two men disliked each other at sight. De Forest had heard rumors of the amplifying discovery made by a Columbia student and he was itching with curiosity. Armstrong was prepared to satisfy that curiosity only to the extent of making one of his closed-box demonstrations, with the additional precaution of keeping the box in a closed room. De Forest had been enjoined only a few years before from making an electrolytic detector that

he had observed one day in Fessenden's laboratory and, with a few changes, had promptly patented for himself. Armstrong was taking no chances.

De Forest described the Columbia meeting years later in his autobiography. He described how Armstrong, wrapped in deepest mystery, had a concealed box in an adjoining room into which neither he nor his assistant, Charles V. Logwood, were allowed to peek. "But when he, Armstrong," wrote de Forest, "led two wires to my amplifier input to demonstrate the squeals and whistles and signals he was receiving from some radiotelegraph transmitter down the Bay, C. V. and I thought we had a pretty fair idea of what the young inventor had concealed in his box of mystery."

If de Forest had any idea of what was in the box on that fall evening of 1913, he was keeping it a deep secret from all the world. Neither on that occasion, before numerous witnesses, nor on any previous occasion, had he demonstrated any real amplification of wireless signals by his audion tube. It was, perhaps, in the evil nature of things that the two men should become bitter enemies. De Forest in the seven years since he had patented the audion tube had derived little of great worth either technically or financially from it, being unable to show that it would do much more than any other detector. Harassed by debt, skipping nimbly from one shaky enterprise to another, he was then working as a research engineer for the old Federal Telegraph Company while trying to reorganize his forces in a company of his own. Armstrong appeared then as the man who was about to take from him the prize development that would make the audion a commercial success. Indeed, Armstrong already had done just that, legitimately, by the power of his own mind in analyzing physical phenomena. De Forest, if his subsequent actions are any guide, returned to his laboratory from this fateful meeting in the fall of 1913 to hunt frantically for some means to head off the new development.

Armstrong went imperturbably on studying all the ramifications of regeneration. The school year of 1914-1915 was a time of great fruition for him. He worked straight through the summer of 1914, while John Armstrong led the family on a long-promised grand tour of Europe. His instructorship had run out, but a one-year fellowship was found for him that allowed him to put in full time in Pupin's laboratory, where the two at once began a basic investigation of static, the most troublesome problem in all wireless communications, that was to occupy them for years to come. On October 6, 1914, a little less than a year after filing for his first patent, Armstrong was issued U.S. Patent No. 1,113,149 on the regenerative receiver circuit, a patent as historic as the first Bell telephone patent and as clearly decisive in the development of the modern world.

By then, however, the First World War had broken out in Europe, sending the Armstrongs scampering back to the U.S., and there began a derangement that was eventually to engulf nearly all human affairs. In October, the month his patent was issued, Armstrong was drawn into an incident of the war with liveliest consequences. The British had cut all German cable communications. This left the German embassy in the U.S. dependent on a single wireless station, the German Telefunken station at Sayville, Long Island, operated by the subsidiary Atlantic Communication Company, which like all other wireless stations of the time could not get signals reliably over such distances. But Atlantic Communication had witnessed a demonstration of Armstrong's equipment early in the year, arranged by Professor Arendt, who knew its president, Dr. Karl G. Frank, and Frank offered to take a license under the patent if Armstrong would rush his apparatus out to the station to establish communications with Germany. Howard carried the whole apparatus down to Sayville on a late evening train and worked through the night to get it ready for the morning schedule. Promptly at

six A.M., Nauen, Germany, came in clear and strong, and the station remained constantly in touch with Germany until the U.S. entered the war in 1917.

No more dramatic demonstration could have been devised to illustrate the power of Armstrong's regenerative invention. It made the front pages of newspapers—Armstrong's first appearance in the press—and overnight the feedback circuit became the sensation of the wireless world. Late in the same year, having by then assembled enough data, Armstrong was ready to make a full scientific report on his invention to the engineering world. Sometime in the year before he had managed, through Charlie Underhill, to get some improved "hard" tubes—tubes more thoroughly evacuated than the early audion, which was a "soft" tube with residual gas left in its imperfect vacuum—and with these tubes he got better results and more accurate measurements. In December, 1914, he published in *Electrical World* a definitive paper on the "Operating Features of the Audion." This was followed early in 1915 by a paper delivered before the Institute of Radio Engineers entitled "Some Recent Developments in the Audion Receiver," later printed in the I.R.E. journal. He also addressed the Radio Club of America, in which he was increasingly active, on "The Regenerative Circuit."

The significance of these modestly titled papers is that they marked the practical beginnings of the age of electronics. For the first time, with great clarity, force and a minimum of mathematics, the physical action of the three-element vacuum tube was correctly explained. The December paper conclusively proved that when a negative charge was applied to the grid, the plate current decreased, and when a positive charge was applied, it increased, demolishing de Forest's theory that no alternating current was to be found at the plate. For the first time, a characteristic engineering curve was diagrammed to show how the tube amplified. These curves were substantiated by a painstaking series

of oscillograms made with the assistance of Professor Morecroft at Columbia. For the first time, the mysterious action of the grid, acting as a capacitor to vary or modulate the flow of current from filament to plate, was made crystal clear. Finally, the re-inforcing action of the regenerative or feedback circuit in both its amplifying and oscillating phases was described in great detail and a variety of configurations.

All this was explained in terms of a flow of electrons, boiling out of the hot metal filament and streaming across the gap to the positive plate, being alternately modified and built up by varying charges on the intervening grid. Armstrong drew here upon all the latest findings in physics having to do with electron emission from a hot metal cathode in evacuated tubes. Armstrong was the first, however, to explain these electronic currents in the three-element tube and to show how they could be put to work, in broad physical terms that became the commonplace tools of electronic engineering, valid from that day to this.

In the excited meetings of the Institute of Radio Engineers through the fall of 1915, at which the astonishing import of these papers was discussed and argued, de Forest was constantly on his feet attacking both the methods and the conclusions as erroneous. He still held to his key position that "a positive as well as a negative charge will reduce the plate current." He ridiculed Armstrong's smoothly drawn curves on characteristic tube performance—curves that were to become one of the most familiar tools of modern radio engineering—insisting that these curves ought to have "wiggles" in them. In particular, he attacked the "oscillating audion" as a phenomenon not dependent on the regenerative circuit, invented by Armstrong, but on some other action he himself had observed some time before. The only conclusion to be drawn from these heated discussions, fully reported in the I.R.E. journals of the time, was that the inventor of the

audion tube still did not understand his invention or how it worked.

Yet trouble was brewing. Indeed, it already had appeared, as was almost inevitable for an invention as important as the regenerative circuit, around which many investigators had been buzzing. Almost as soon as Armstrong filed for his first patent late in 1913, three other candidates arose to claim the same or a similar invention. The first of these was Irving Langmuir, the great research scientist of the General Electric Company, who had made important improvements in the vacuum tube and who, in fact, had arrived independently at regeneration some time after Armstrong. By a remarkable coincidence, Langmuir filed for a patent on exactly the same day that Armstrong filed for his, a fact of only curious interest since priority depends not on the date of filing but on the actual date of invention. The second claimant was a German named Alexander Meissner, who on March 16, 1914, filed an application on a regenerative circuit employing a gas-relay tube. Armstrong quickly established his priority over these two in the Patent Office proceedings that followed, though Langmuir was so close behind him that it was clear that if Armstrong had not invented the regenerative circuit Langmuir would have received the credit.

The third claimant was Lee de Forest. He filed two belated patent applications at widely separated intervals which were of such a nature that they were promptly involved in tangled interference proceedings in the Patent Office with Armstrong's pending application on the regenerative circuit as a transmitter. These proceedings were to go on for the next ten years without the issuance of any patent to de Forest and eventually give rise to one of the most complicated and exhausting patent suits in the history of U.S. jurisprudence.

The first of de Forest's applications was dated March, 1914, some six months after his brush with Armstrong at Columbia. It claimed the invention of a circuit called the "ultra-

audion" which would do what the Armstrong circuit did, both as a receiver and transmitter, but without recourse to feedback or regeneration. De Forest repeatedly disclaimed any regenerative features. The "ultra-audion" proved upon examination, however, to be a limited feedback circuit. Its circuit diagram was so confusingly drawn as to obscure the fact of regeneration. As later revealed in laboratory notes, de Forest's assistant Charles Logwood had stumbled on a circuit arrangement which—without a tuning element in the tube's output circuit, the key controlling factor in achieving a full amount of feedback—gave a very limited and clumsy form of regeneration.

De Forest's second patent application was dated September, 1915, nearly a year after Armstrong's two historic papers on the regenerative circuit, which were the first published explanation of how the vacuum tube really worked. In this application de Forest boldly claimed the prior invention of radio-frequency regeneration in all its aspects. Embodied in its specifications were all the latest findings on regeneration as revealed in Armstrong's papers, somewhat rearranged as to circuit diagrams and changed about in language. These were the same findings that de Forest was even then attacking as erroneous before meetings of the Institute of Radio Engineers. Embedded in his application, however, was a broad claim to the invention of the "oscillating audion," and this was sufficient to hold up the issuance of Armstrong's second patent covering the oscillating feature in interminable interference proceedings.

This was the beginning of a nightmarish new world to Howard Armstrong and not the one he had dreamed of out of his attic window over the lordly Hudson. In the midst of it, his father died. While surf bathing at Beach Haven, New Jersey, where the family had decided to spend the summer of 1915, John Armstrong suffered a stroke and was dead by the time he was carried ashore. Howard went down to meet

his shaken family at the railroad station, for he was again working through the summer, and suddenly found that he was the head of the family. He also found in the days that followed that his father was far from being as wealthy as he, in his innocence and absorption in wireless, had always supposed. The discovery was a shock. There was, in fact, little to carry the family forward now except his own earnings.

His earnings up to then had been meager, so meager that he was in the habit of frequenting a cheap restaurant near Columbia where even the cheapest meals were accompanied by all the bread and rolls one could eat. Except for the license to the German-owned Atlantic Communication Company, which was bringing in about $100 a month, his invention was not earning enough to cover the expensive patent proceedings going on in Washington. At the time this license was taken, Atlantic Communication offered to buy the patent outright. A letter survives in which William Davis, the patent lawyer, presented terms. "Mr. Armstrong," he wrote, "has discussed with me your letter of November 11 [1914]. He is prepared to sell the entire right to his patent and pending application, covering the receiver, for the sum of $50,000." That apparently was too steep a price.

In this hard-pressed period Armstrong would have gladly settled for a small, flat sum on his invention that was to be worth hundreds of millions of dollars. But no one came forward. Nothing was heard from the other companies that had witnessed his demonstrations. Not that they were entirely myopic as to the full revolutionary implications of his invention, but they were waiting about to see whether some other alternative might turn up, possibly in their own laboratories, on which they would not have to pay toll. Corporations have always had a curiously ambivalent attitude toward inventors and the patent system, which they regard as a great bulwark when it is protecting the monopoly right of patents owned by themselves but a great nuisance when it upholds

an independent inventor in his search for gain. It is a significant commentary on the American scene that the first and, for nearly two years, the only licensee under Armstrong's historic regenerative-circuit patent was the German Telefunken Company, parent of Atlantic Communication.

While commercial interest lagged, amateurs picked up the feedback circuit and swiftly spread radio operations to amazing lengths. In this fraternity Howard quickly became known as "Feedback" Armstrong. Through 1915, operations moved exuberantly out from local areas, where they had been confined for so long by weak signals and poor reception, to link up amateur stations from coast to coast. The air at night was filled with the chatter of amateur "keys," and a few stations, including one built by de Forest, regularly played gramophone records for the delectation of all-night initiates. Nearly all the pioneering of radio broadcasting, then unrecognized as a commercial opportunity, was thus carried out in home closets and attic cubicles with home-made equipment on which no one attempted to collect royalties. There was still a great industrial development needed before broadcasting could be put on a reliable basis, but it was the amateurs who showed the way.

The only signficant commercial development in this period was the inauguration by A.T. & T. of the first trans-continental telephone service, in time for the International Exposition at San Francisco in 1915, employing audion tubes as the indispensable amplifying units on the line. Later that year A.T. & T. launched the first long-distance experiment in radiotelephony between Arlington, Virginia, and Paris, France, employing the regenerative circuit both in banks of audion tubes as transmitter and in smaller equipment as receiver. A.T. & T. had moved very fast in development, within its sphere of interest in point-to-point telephone services, completely ignoring Armstrong. Moreover, it had quietly decided to build on its initial 1912 investment in the

de Forest patents by acquiring in October, 1914, additional assignable rights under these patents for radio signaling. And in 1917 it was to cap this by acquiring all remaining radio rights under the de Forest patents, issued or pending, including the two in interference with Armstrong's, for $250,000. More than half of this sum was promptly swallowed up in de Forest's corporate enterprises, which retained only the right to manufacture audions for amateur and experimental purposes. A.T. & T. could have acquired Armstrong's patent outright for much less than this, considering the straits he was in, but A.T. & T. made no move to do so.

Armstrong resolutely sought to raise his income, confident that his patent and his solid scientific contributions to the understanding of electronics, which had swept around the world, constituted the only valid claim to the discovery of regeneration. He not only needed cash to support the family, but heavy legal expenses were looming in the inevitable court test for which de Forest obviously was sparring. He was determined to support himself, so far as he was able, as an independent investigator and free agent. Involvement in the type of commercial enterprises that were the Edison and de Forest pattern did not attract him. He believed that the creative engineer should remain independent of all commercial bias and control. The freedom of the university laboratory, with Pupin's as a model, was deeply in his blood. Industry should be willing to pay for whatever of worth he was able to bring out of his investigations.

By 1916 his difficulties began to clear. Pupin had raised him to assistant by then and helped him over some of the early financial hurdles. It was then plain to nearly everyone that transoceanic and long-distance wireless communications could not develop except through the regenerative circuit, on which Armstrong held the only clear and issued patent. Indeed, regeneration was the very heart of the action in the vacuum tube. The American Marconi Company finally con-

cluded a license under the patent in April, 1916, followed by others. By 1917, royalties began to come in at the rate of about $500 a month, which was no fortune but at least was a beginning.

All this was a marking time. Relations with Germany were fast deteriorating. With the intensification of German submarine warfare in the spring of 1917 and the sinking of American merchant vessels, the U.S. was suddenly in the war. Wireless and the career of Howard Armstrong were thenceforth to be wrenched out of their old channels into an entirely new phase of development.

Chapter 7

The Signal Corps Major

IT IS DIFFICULT to recapture now, after two world wars and four decades of unremitting disenchantments, the air of noble purpose with which the U.S. went to war in 1917. It was an air suffused with a purple aura, a sentimentality, a kind of bouncing adolescent idealism that has set succeeding generations' teeth on edge. From the age of the atomic bomb and the supersonic jet, this "war to end wars" appears to have been enacted within the set scenes of a faded, tragic musical comedy. Tall maidens in sweeping frocks clasped doughboys under the trees and, in the words of a popular song of the era, smiled the while they kissed a sad adieu. Even the uniform, from its stiff campaign hat down to its rolled puttees, holding over from the Spanish-American War, had a gawky, sentimental quality. Yet the clash of issues and of men had no less a timeless passion than all tragic wars before or since.

Armstrong had an old-fashioned type of patriotism that responded quickly to such crises. It was of the unostentatious sort, strongly attached to the native soil and fed by the currents of American history, one of his favorite forms of reading since boyhood, with none of that rancor, political edge or fervid display that characterizes so many latterday manifestations. He had never thought much about politics. He was a Republican by Protestant Presbyterian background, a Progressive from having come up to voting age through the years of Teddy Roosevelt's muscular but mild apostasy,

and he would never stray far from that loose body of libertarian belief. The new President, Woodrow Wilson, was a spindly college professor and a Democrat, but almost no one would question the justness of his call to arms or its necessity. Armstrong, along with a legion from the silent fraternity of skills and professions, was anxious to get in it.

The Radio Club of America, to which he had been elected president in 1916, was swiftly melting away, its operations suspended for the duration, with only Tom Styles left as secretary in charge. The radio amateurs of the country were flocking into the U.S. Army Signal Corps, as well as into the Navy, to staff its training schools, laboratories and field stations in a feverish expansion of this new branch of military communications. Armstrong, whose fame in the fraternity was by then well established, was offered a captaincy and in no time at all was in the Army. He assembled what funds he could, gave "emergency" sums into the keeping of his sister Ethel and Aunt Rissie, arranged to have royalties paid into an account on which his mother could draw, packed up and was off. To a degree, it was a release. The war halted for the time being the patent litigation and commercial maneuvers, speeded up radio development and, among its more curious fruits, gave him time for another intensive bout of creation.

With only a minimum of officer's training in the summer of 1917, Captain Armstrong was shipped off with an advance unit to Europe to aid in the problems besetting the establishment of a communications system then in its military infancy. He was then going on twenty-seven, already prematurely bald, but slim, broad-shouldered and rangy. In his trim khaki uniform, worn with a dash that was part of his nature, he was as handsome as he would ever be. His first letter home, dated from Southampton, England, on October 28, 1917, was characteristically breezy.

"Dear Mother," he wrote. "Crossed safely on an American

liner that Pop has travelled on many a time . . . As you can imagine I looked up the radio at the beginning of the trip and had the good luck to find an old timer in the chief operator . . . The ordinary ship receiver does not carry audions but the operator happened to have one of his own aboard so I borrowed some wire from the electrician and rigged up a regenerative circuit that brought in signals from all over the map. We got press from both sides of the Atlantic which is unheard of in ordinary ship practice." This was only an indication of the slowness with which a new idea penetrates commercial practice and a foretaste of the conditions Armstrong was to find in the American Expeditionary Force's wireless set-up.

Three days of bad weather held up the ship at Southampton, and Armstrong, growing restless, slipped off one evening for a night in London. On the way to a hotel he ran into Marconi House, headquarters of the British Marconi Company, on the Strand. Though it was late, this was an opportunity he could not miss. Going in, he managed to raise a young engineer who was still about named Captain Henry Joseph Round, himself a brilliant developer of early radio circuits, with whom Armstrong had late dinner, watched for a Zeppelin raid and talked wireless into the dawn. From Round he learned that one of the problems occupying the best Allied technical brains at that time was the detection and amplification of what were then very high frequency signals in the 500,000 to 3,000,000 cycle range. The Germans were suspected of using these high frequencies to keep their field communications out of Allied hearing. Armstrong also learned that British vacuum-tube development was considerably ahead of the U.S. Round had managed, by an exceedingly ingenious arrangement, to get radio-frequency amplification up to the 1,200,000 cycle range, a feat then beyond the capacity of U.S. vacuum tubes. In fact, U.S. authorities had not even begun to conceive of the need,

and the equipment being shipped to France was totally inadequate for any straightforward solution of the problem Round was posing.

Armstrong's ultimate destination was Paris, where he arrived a few days later, carrying this fascinating new problem in his mind. He could not get to it immediately, however, for first he had to get settled in quarters and then get his laboratory underway. The Signal Corps had set up a development laboratory in a rambling, once elegant old mansion at 140 Boulevard Montparnasse—plush quarters for the slogging trench war of 1917—and Armstrong was assigned a section of this, along with other brilliant, young wireless experts. Almost at once he was rushed off to the front for an inspection of French Army signaling methods, and again the problem of detecting extremely weak high-frequency signals was brought forcibly to his attention. Upon his return, he wrote a report to the States, for the problem was one of such a broad nature that the base laboratories should be working on it. Yet it teased at the back of his mind.

The first weeks were indescribably busy and chaotic. Armstrong and his staff helped build two transmitters and practically rebuilt the A.E.F.'s wireless communications system, which was innocent of vacuum tubes, not to mention the regenerative circuit. As winter came on, he was given the additional task of aiding in the development of an aircraft communications system for the nascent U.S. Air Force. This was both dangerous and uncomfortable work, for the only way it could be accomplished was in endless air tests. Armstrong was assigned a number of planes and pilots and was aloft in every break of the weather, secretly reveling in the speeds and altitudes to which this new form of transportation carried him. In the open-cockpit, canvas-and-matchstick flying machines of that era, however, delicate adjustments in crude radio apparatus had to be made with bare hands at numbing temperatures and there was no assurance whatever

of returning from any flight. A photograph of that time shows a two-place flying Jenny with a helmeted Armstrong waving from one cockpit and from the other a pilot who, on another mission the following day, never returned.

He kept all grim details of his work from the family, but did not cease to direct their affairs as well as he could from afar, in the midst of labors that often found him with little sleep for many days. His income still worried him and outgo had to be watched. As soon as he was settled in Paris he was writing: "The cost of living over here is rather high . . . but so far as I can see I will have no other expenses to amount to anything and will probably be able to save at least half my pay . . . I am enclosing my address and would like to know as soon as possible the state of my bank account and what payments have been made by the Marconi Co. Also about what you find your living expenses are running per month. I want this because it looks like a long war and I want to do some figuring . . . I wish you would send me a couple more cans of shoe polish and a box of grease. Incidentally, have you all the coal you need?"

In the same month he was writing to Ethel: "Have you had the rail put on the cellar steps yet? If not, do it immediately, regardless of what kind of argument you start. Second, is mother working too hard? See to it that Tommy does the snow shoveling etc. You can tell Crick that I didn't ask whether she was working too hard. What's the use of asking foolish questions."

He could be tart. His doting mother passed out his address to a legion of friends and acquaintances, whose letters it was a burden to answer. "Have not rec'd any letter from Mrs. B—— yet," he wrote, "but will answer one, as that is all I can possibly do. Please explain that I am not in any trenches, have a perfectly safe job, and do not require any mental, spiritual or other kind of guidance at the present time but that if she has any advice on how to get rid of the static

and how to prevent the Boche wireless from interfering with ours to send it along. Otherwise please cut out at least one of the horrors of war. Love to all. Howard."

Late in 1917 there appeared on his staff a belated recruit in the person of Sergeant Harry W. Houck, a Pennsylvania Dutch boy from New Cumberland, Pennsylvania, a tiny town just south of Harrisburg. He, too, was destined to be added to the long list of friends and associates whom Armstrong drew around him over the years. Houck had been an eager young wireless "bug" in the fastness of New Cumberland and had been assigned to report to Captain E. H. Armstrong at 140 Boulevard Montparnasse, Paris. He arrived there late, under fantastic circumstances. As he stood before Armstrong and snappily saluted, he was wearing a uniform half French and half American, and officially had been pronounced dead. On landing in France, he had been taken violently ill and had been rushed into a base hospital where the ministrations were none too solicitous. In a delirium one night, Houck wandered away across the fields and woke up in a French hospital more to his liking, with two French doctors bending attentively over him. When he was released two weeks later, he gave his base hospital a wide berth and hopped a truck for Paris to report for duty, per orders. There he discovered that the base hospital, in one of those mix-ups peculiar to armies, had reported him dead and had so notified his family and Captain Armstrong.

Armstrong was charmed by all this and by the perseverance that had carried Houck to Paris and began questioning the new recruit to find out how much he knew about wireless. Asked to draw a crystal circuit, Houck quickly complied. Then, anxious to show off his knowledge, he volunteered that there was a new and better one than that, and he swiftly sketched in a feedback circuit. Armstrong gravely watched, quietly switched two lines about which Houck had reversed in his excitement, and asked where he had heard about it.

"In *Wireless World*," said Houck, "and d'you know, Captain, the feller who invented this has the same name as you!"

The new sergeant turned out to be a craftsman in the building of apparatus meticulous enough to suit even Armstrong, who was a stickler for cleanness and compactness of design. Moreover, he had the patience, enthusiasm and stamina to match Armstrong's disregard for time when in pursuit of a problem. In after years Armstrong would allow no one else to build his transformers, maintaining that Houck had a "touch" with transformers superior to anyone he knew. In addition to this, Houck had a sound streak of originality, capable of following new ideas and carrying them out on his own. Early in 1918 in France, the two were soon in pursuit of the problem which, through all the pressures of other work, Armstrong had been turning over in his mind ever since his talk with Round.

The essential problem was how to detect and amplify an inaudible high-frequency signal, many hundreds of thousands or millions of cycles above the threshold of human hearing, and then bring it down within audible range. After a good deal of vain thinking, in which he put aside the original problem as presented to him, Armstrong was lead to a solution by an extremely roundabout route. Early in 1918 the German air force stepped up its bombing raids over the capital. Armstrong liked to get out and watch these raids, as a small boy likes to chase fires. The dangers were not very great by present standards, for the bombers' clumsy missing of targets was more than matched by the wild inaccuracy of early anti-aircraft fire. One night while watching a particularly lurid display from one of the Seine bridges Armstrong idly speculated whether the accuracy of anti-aircraft fire might be improved by finding a means of detecting the extremely short electrical waves put out by an aircraft engine's ignition system and then using these signals as a direction-finder. Walking back to his apartment that night, Armstrong

reached a street that, many years thereafter, he vowed he could find in the dark if set down in Paris blindfolded, for he was struck there by an idea as momentous as the one that had occurred to him on a Vermont mountainside not six years before.

Suddenly three unconnected observations and events joined in his mind: his talk with Captain Round in London; a study of a radio phenomenon he had made at Columbia University just before entering the Army; and now this contemplation of amplifying waves radically shorter than any that had ever been considered before. All this came together to suggest a method by which the whole shortwave reception problem might be solved, within the limits of the low-frequency tubes available to him, a limitation that bounded and gave rise to his solution. Working tremendous hours, he built and tested step by step a complicated eight-tube receiver, requiring extremely skilled adjustment, in which detection and amplification of weak shortwave signals were carried to heights never before reached. Where the regenerative circuit amplified signals up to about one thousand times, the new circuit increased this by several thousandfold, with unprecedented stability, selectivity and quietness.

A typically guarded hint of this new development was contained in a letter home late in February. "In addition to aeroradio," he wrote, "I have been doing a lot of ground work during the bad weather and some of it looks pretty good . . . By the way, I need Gillette razor blades, summer socks and summer underwear, also grease. No particular rush but in the near future. Likewise I need that plum pudding you promised me for Xmas. Voila. I would very much like to get copies of the *Wireless Age* from the time I left the States to date and would appreciate it tres beaucoup . . ." (The mysterious grease which Armstrong requested so frequently remains something of a mystery, none of his family or friends being able to recall it.)

Through the brutal spring and summer of 1918, when the German armies were thrashing about in the last desperate hemorrhage of the war, Armstrong pushed his experiments. The need for such a development, not only to detect enemy signals but to improve Allied communications, had occupied nearly all the leading Allied experts. Field tests through the summer showed that the young American Signal Corps captain had the answer. General Ferrié, the head of French military communications, made the Eiffel Tower available for more extended experiments. A steady parade of technical officers and frock-coated French savants visited 140 Boulevard Montparnasse to study the new circuit, which its inventor called the superheterodyne. But before it could be further developed, the war ended with a crash on October 5, 1918, in the breaching of the Hindenburg Line. The superheterodyne was never put to the military uses for which it was originally designed, either as a direction-finder or as an amplifier of secret German signals, which proved to be nonexistent. But in due course it was to become the heart of all modern radio receivers.

With the signing of the armistice on November 11, many months of work in Paris still remained. A.E.F. communications, which had been among the most advanced units on the scene, was necessarily among the last American units to be withdrawn. Armstrong had to clean up his laboratory work, aid in the establishment of a line of communications into Germany and carry the superheterodyne to the stage where the Signal Corps could move on with its military development. Many technical meetings had to be gone through, and the stream of distinguished visitors hardly abated. Late in the fall, Captain Round came over on a tour of British installations and there was a grand reunion and another night of excited talk, over Scotch-and-sodas, with the man who had set Armstrong off on his latest discovery and with whom he

was to carry on a warm association for the next thirty years or more.

This visit precipitated an unusual incident. To transport his guest about Paris, Armstrong requested a military car from a motor depot commanded by a young Texas officer who was becoming increasingly fractious about supplying the young "radio wizard" with transportation for his stream of visitors. The officer sent a battered army truck over to 140 Boulevard Montparnasse. Armstrong took one look at the truck and in a sudden towering rage roared back to the motor depot with it, sought out the Texan and flattened him to the pavement with one blow. Ordinarily mild tempered and not easily ruffled, Armstrong could flash up to formidable anger when provoked.

His mind was then in a state of high tension. At that time the U.S. Army allowed inventions made in its laboratories to be retained by the inventors, and there was no time to be lost in securing a patent on the superheterodyne. Early in December Armstrong sent a letter to his mother, heavily underlined at crucial points. "Last week," he wrote, "I cabled you to cable my account Guaranty Trust Co. Paris one thousand dollars. I have not received it to date but guess you got the cable O.K. If you did not get a cable dated in November asking for $1,000 to my account Guaranty Trust Paris please cable the money at once. Also, if you get another cable for a different amount at any future date please cable that at your earliest opportunity. The reason for all this is that I am trying to protect an invention which I have made over here and due to the peculiar international complications with the French I want to have enough money on hand to be prepared for any emergency . . ."

The application for a patent on the superheterodyne was dated December 30, 1918, in Paris, France. Because of time lost in transit and in legal mazes, this application was not filed in the U.S. Patent Office until February 8, 1919. From

this application, however, there was to issue with unusual alacrity on June 8, 1920, U.S. Patent No. 1,342,885—another historic milestone in radio.

Though he now had two important inventions to his credit and the first of these had seen wide use through the war, his income was more reduced than ever. His only licensee in this period was the American Marconi Company, which paid him regularly through the war, a sum totaling about $5,700 over a span of two years, but this was hardly big enough to remove the pinch of current as well as foreseeable expenses. "Draw positively everything you need from my account," he wrote to his mother. "By all means be sure you do not go short on food because that is absolutely the poorest way to economize. I didn't like the high prices over here at first and cut down on quality but it didn't pay . . . Before drawing on my account if either Ethel or Rissie have anything left of what I gave them before leaving I think they ought to use it because I am going to have some very heavy lawyers' bills after the war and will need everything I can lay my hands on . . ."

The radio industry obviously was ready to be born after the forced labor of war, and this interim in Europe, he felt, was a golden opportunity to meet the influential men in the field and to secure, if he could, European licensees. He was again writing to his mother late in 1918: "Now in regard to finances I have considerable trouble in view and the situation is considerably complicated over here also. I am going to try to swing a deal before I come back with a Baron and a few other such like gentlemen if it is possible and I think it is. Hence I am going to draw 5,000 francs from my account in the Corn Exchange Bank so you will understand why you have less money than you think is coming to you next time you have the book balanced . . . The next year will determine if I am completely cleaned out or retire . . . You may be interested to know that de Forest is over here now and

will report to me before a great while. Don't say anything about this outside of Ethel and Rissie. If he had come over before the armistice was signed one or the other of us would have stayed in France but at present I guess he is fairly safe." Nothing came of the deal with "the Baron," and Armstrong missed de Forest, or *vice versa,* but the weight of that impending contest, now that the war was over, bore down upon him.

Paris was inexpressibly slattern and gay in release from the long tensions of war. What with one personal pressure or another, Armstrong did not have much time for play, though he liked gaiety and conviviality in his moments of relaxation and, under the grip of accomplishment, had lost part of his shyness. Christmas of 1918 he celebrated with "turkey and all the fixings except cranberry sauce" and a noble plum pudding which the family managed to get to him in time from Harrod's of London. With him was a young soldier from the Yonkers area named Bradley Hammond, who was to marry his sister Ethel on his return to the States and who slipped into Paris A.W.O.L. for the holidays, dodging military police all the way. "However," wrote Howard reassuringly to the family, with teasing humor, "now that the war is over, it is a crime to be absent without leave in Paris only if you are caught—and he wasn't . . . It was a dinner that we would have broken all the army regulations ever made to have under the circumstances, but we only had to break about half. After this we walked around town, saw a few policemen, had a light supper and went to see a little French girl of B's. B. will tell you all about it as he will be home before me."

Despite the note of ease here, he was extremely busy. In February, 1919, he was raised to the permanent rank of Major for his distinguished contributions to wartime wireless. About the same time, he stood stiffly one morning with a line of American officers on the damp, gray cobblestones

before the Palace of Justice to receive from trim, gesticulating General Ferrié the medal and ribbon of a *Chevalier de la Légion d'honneur*. He also was invited to instruct at the University of Paris and to deliver two notable lectures—one on the regenerative principle and the other on the superheterodyne—before a large audience of French scientists at the Sorbonne. By far the most prized honor that he had received in the whole war, however, was a medal from the Institute of Radio Engineers in New York. This was the Institute's first Medal of Honor, the highest award to be made in the field of U.S. wireless communications, presented to him for his invention of the feedback circuit, an award that was to have a highly melodramatic history.

Meanwhile, spring passed into summer, and still he was held up in France, writing an apologetic letter to his youngest sister Cricket, who in her turn was graduating from college. "At the present time I am very much afraid I won't be home before August but will certainly make it by the first of September so guess that the main event will not be held up by me. Life in Paris just now is fairly lively but I have been so busy lately that most of the interesting things went by without my having a chance to see them. A few days ago however I took the time to watch some of the tennis at the Racing Club in the Bois de Bologne and saw Gobert, the French champion, and the great Mlle Lenglen. This little mademoiselle won the championship of France before the war when she was 17 years old and she is a little peanut like someone I know in the U.S.A. . . ."

That summer he took off by automobile for an inspection tour of the new A.E.F. communications network that led him through Coblentz, Cologne, Spa, Antwerp, Brussels and back to Paris. At Spa he was in the basement of Hindenburg's château, the former German Army Headquarters where the armistice commission was sitting, inspecting the regenerative equipment that was keeping the American dele-

gation in direct touch with the U.S., when the operator turned to him. "Major," he said, "there is a cable coming in for you from a lawyer in New York named Davis, d'you want to take it?" Armstrong slipped on the headphones and took the message: "De Forest pressing action. Your presence urgently required."

There was now no putting off the return to the States as soon as he and the Army were able to manage it. De Forest had returned to the attack in Washington before a U.S. Patent Office tribunal, seeking to knock out Armstrong's still pending regenerative oscillating-circuit patent in interference proceedings. Moreover, the De Forest Radio Telephone and Telegraph Company, which had reached a high state of solvency selling audion equipment to the military during the war, was now boldly moving forward in the use of the regenerative circuit without so much as a bow to the Armstrong patent, still the only patent issued in this field. Other and bigger companies in the electrical and communications industries, also largely ignoring Armstrong's patent, were locked in mighty negotiations to reorganize the wireless business, which appeared to be entering a new and more lucrative phase of development. It was high time for Armstrong to be getting back to the U.S.

Late in September, 1919, Mrs. Emily Armstrong, rocking vigorously on the porch at 1032 Warburton Avenue, Yonkers, saw a strange military figure with a swath of bloody bandages on its head turn up the walk to the house.

"Don't be frightened, Mom," it said, "it's nothing at all, everything is all right."

In a last, outrageous fillip of the war, Armstrong had contracted at Cherbourg, the port of embarkation, a severe anthrax infection on his head, which a clumsy ship's doctor had lanced and made worse. He was well out of it, however, well out of a war that, in the brief time the U.S. was in it, had rolled up over one hundred thousand fatalities and left the

world never more the same. With his bandages still on him, Armstrong slept that night in his old bed in the attic, with the dusty wireless gear all around him, back once more where he had started from. He was a fortnight in the hospital, getting his infection taken care of, before he could pick up again the battle of his life and get on with the development of the superheterodyne.

Chapter 8

The Superheterodyne Feat

THE SUPERHETERODYNE circuit was a brilliant display of Howard Armstrong's genius for taking up seemingly unrelated facts and combining them, by intuitive thinking, logic and hard work, into new instruments of amazing effectiveness. The superheterodyne was not quite as basic an invention as the regenerative circuit, but it was a fundamentally new manipulation of electromagnetic waves so deft as to appear almost a feat of sleight-of-hand. Even now, to the ordinary man, uncalloused by too much technical knowledge, it still appears as a magical box of tricks. To understand how it was accomplished and what it meant, it is necessary to go back a bit into some of the fundamentals of radio.

Electrical waves rippling out from a transmitter have many of the properties of waves seen upon a body of water, including their beauty, symmetry and sinuosity of movement. They also share those measurable properties by which a wave is defined: amplitude, the amount that a wave rises above or dips below its base line, indicating its volume; frequency, the number of waves that pass a given point per second, indicating the speed of the up-and-down or oscillating cycle; and wavelength, the distance from crest to crest, which is another way of expressing frequency, i.e., the higher the frequency the shorter the wavelength. But whereas water waves are relatively heavy and sluggish, electrical waves, being composed of invisible almost weightless electrons, move with the speed of light. Hence they vary over an infinitely higher

and broader range of measurements than ocean waves. In frequency alone, radio waves range from 10,000 up to 1,200,000,000 cycles or complete waves passing a given point per second. Engineers, for convenience, express these numbers in kilocycles or thousands of cycles per second (e.g., 1,000 cycles equal 1 kilocycle) and in megacycles or millions of cycles per second (e.g., 1,000,000 cycles equal 1 megacycle), but for consistency at this point we will stick to simple cycles. The whole range of radio frequencies, each of a different wavelength, is known as the radio spectrum and represents the multiple-lane highway on which all radio-electronic devices operate.

The earliest wireless, with no accurate means of determining wavelength, probably operated on waves just under 2,000 meters in length. These were loping mile-long waves, hugging the earth. Wireless started in this longwave, low-frequency region of the spectrum because there was no way to get waves of sufficient power at higher frequencies from the spark-gap and other early transmitters of the time. Every major shift upward in frequencies to shorter wavelengths entailed the development of new levels of power and new instruments. Not until the vacuum-tube oscillator was developed after 1914 was it possible to generate any reliable continuous-wave power above 100,000 cycles. Even at the end of World War I, however, commercial wireless was still operating at much lower frequencies and even longer wavelengths—waves up to six or seven miles long—because the most stable generators were still in these frequencies and it had been found that very long waves somewhat improved daylight reception. Much wartime research employing the vacuum tube had been done in the shorter waves above 100,000 cycles—the region where modern radio was to be born—but the problem of receiving these shortwaves was formidable. At 3,000,000 cycles, or wavelengths of about 100 meters, the upper goal of military research, signals were so weak that

they could not be detected beyond short distances by any known receiver.

It was to the problem of detecting and somehow amplifying very weak shortwave signals that Armstrong applied himself late in the war, anticipating the next decade's development of radio as well as shortwave wireless communications. The regenerative circuit would not work here for two reasons. At its maximum point of amplification, as we have seen, its vacuum tube began to oscillate, becoming a generator rather than a receiver of radio waves. Amplification could not be raised beyond this point, and it was insufficient to bring in weak shortwave signals. Secondly, the vacuum tubes then available could not handle such high frequencies. Henry Round in England and Marius C. A. Latour in France partly got around these difficulties by employing a number of specially constructed tubes in a series, each tube boosting amplification slightly above the previous one. But total amplification was still inherently limited, and the arrangement could not get reception beyond 1,500,000 cycles. Some entirely different circuit was needed to solve the problem.

Armstrong's first thought was for a technical paper he had delivered before the Institute of Radio Engineers in 1917, just before entering the Army, on a circuit known as the heterodyne. The heterodyne principle (from the Greek *hetero-dyne,* meaning two different forces) had been discovered by Fessenden over ten years before in trying to improve reception in his wireless system. This was well before the vacuum tube. The basis of Fessenden's circuit invention was the discovery that if he took a signal of a certain frequency into his receiver, mixed this incoming signal with a higher frequency current generated in the receiver by a carbon-arc oscillator, the resulting signal impinging on the headphones would have a frequency equal to the *difference* between the two currents. Thus an incoming signal of 50,000 cycles mixed with a 51,000-cycle current from a local source in the receiver

would produce an audible "beat" note of 1,000 cycles. This made the receiver more sensitive and helped to smooth out static. But the carbon-arc oscillator was unstable, noisy and cumbersome, and the heterodyne circuit, though it was regarded as one of the most intriguing ideas in wireless reception, remained in the background for years for lack of a good compact oscillator.

With Armstrong's invention of the regenerative vacuum-tube circuit, all this was changed. Here was a reliable oscillator, small and stable enough to make heterodyne reception practicable, and the development of heterodyne receivers employing vacuum tubes rapidly swept through the wireless art. About 1916 a controversy arose as to the exact character of the heterodyne action in vacuum-tube circuits. Not being able to follow all the mathematical gyrations of the dispute, and distrustful as always of mathematics divorced from experiment, Armstrong set out to explore for himself by physical experiment all phases of the heterodyne action. This study was the basis of the paper he presented in the spring of 1917, before embarking for France, and it remains one of the clearest and most exhaustive expositions of the heterodyne principle in radio.

In France later that year it seemed only natural that Armstrong should think of this paper when squaring off against the problem of shortwave reception presented to him by Captain Round in London. The idea of using the heterodyne principle already had occurred to others. It seemed only logical that the problem of getting hold of very weak shortwave signals, by those days' standards, might be solved by heterodyning or beating down the frequency of the incoming waves to a manageable level. He tried it. But the frequencies with which heterodyne receivers had been dealing theretofore were in the range of 100,000 cycles. Signals in the range of 500,000 to 3,000,000 cycles were an entirely different matter. Since these signals were so weak that they

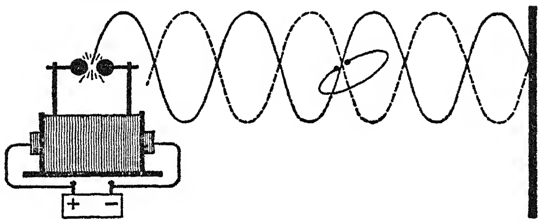
produced no detectable response in the vacuum tubes then available, simultaneously amplifying and heterodyning them came to nothing. Armstrong put the heterodyne idea away and nearly forgot about it in his pursuit of other matters and other methods.

The final clue to the puzzle came in the night air-raid over Paris early in 1918. This incident had the effect of jarring his mind into a consideration of the problem from a different angle in extreme terms. How might one go about detecting the extremely weak high-frequency radiations from airplane-engine ignitions, with frequencies probably in the neighborhood of 10,000,000 cycles or higher? No conventional means of reception with the tubes available—neither feedback nor straight heterodyne nor simple tuned circuit nor series arrangement—could hope to catch these signals. "Suddenly," said Armstrong later, "all three links of the chain joined up and I saw the way these signals could be handled." This statement, unsatisfactory as it is, is probably about as exact a description as anyone is likely to get of the flash of genius in which new ideas are born. Everything moves logically up to a point, then there is a sudden leap into the unknown.

The essence of his idea was to build a four-stage receiver that would reach up and bring down the weak high-frequency waves to a level where they could be amplified and detected by ordinary means. In the first stage a tube would simply take in the signal from the air at 1,000,000 cycles, say, and mix or heterodyne it with a local current of 970,000 cycles, supplied by an oscillator tube, to bring the signal down to an intermediate frequency of 30,000 cycles, the difference between the two currents. This heterodyne signal would still be weak and undetectable, but it would now be at a frequency that the tubes could work on. In the second stage a fixed-frequency amplifier would magnify the signal several thousand times. In the third stage the greatly ampli-

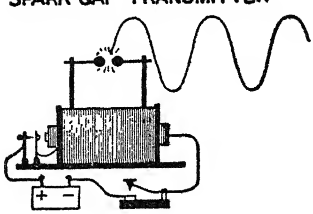
THE PROGRESS OF RADIO

DIAGRAMS BY MAX GSCHWIND

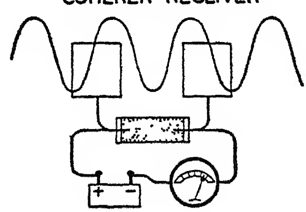


1888: With the simple apparatus above, Heinrich Hertz, a young German physicist, made the epochal discovery of electromagnetic or radio waves. Electrical sparks oscillating between the two metal balls, at left, sent out waves of high-frequency alternating electricity into space. The invisible waves were detected a few feet away by the open copper-wire loop, at right, which sparked in resonance with the metal spheres when properly positioned in the wave train.

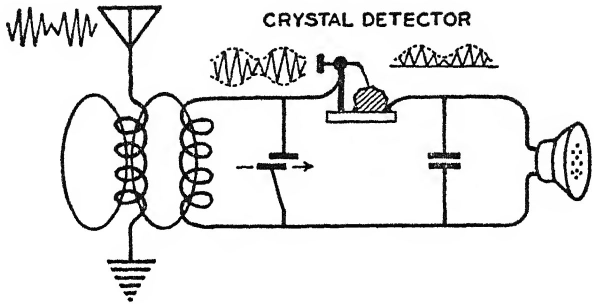
SPARK-GAP TRANSMITTER



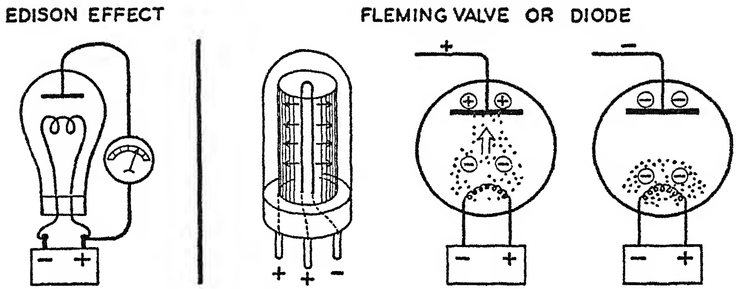
COHERER RECEIVER



1896: Guglielmo Marconi, a young Italian-Irish experimenter, succeeded in transmitting Hertzian waves over a distance of two miles with the apparatus above. He added to Hertz' spark-gap transmitter a high earth-grounded aerial, which sent the waves rippling out over the earth. He substituted for the wire-loop receiver a more sensitive device called a coherer—a tube of loose metal filings that cohered and passed a weak current when struck by electromagnetic waves. In 1901 Marconi sent the first wireless message across the Atlantic.

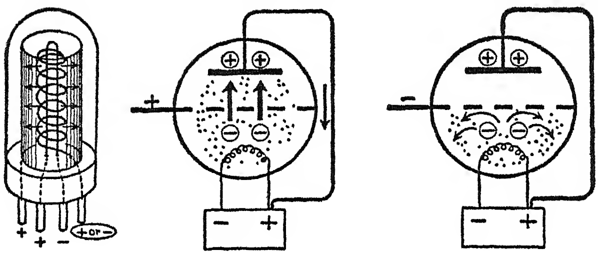


1906: Two Americans, H. H. Dunwoody and G. W. Pickard, almost simultaneously invented the famous crystal-and-cat's-whisker receiver shown in circuit diagram above. In the widespread search for a more powerful wireless receiver, they discovered that single crystals of quartz, galena and other substances had the power to detect wireless waves and pass them on as direct current to headphones, more efficiently than the coherer and other devices. The crystal detector came to dominate all wireless and early radio, but it lacked any means of amplifying the signals, for which the search went on.



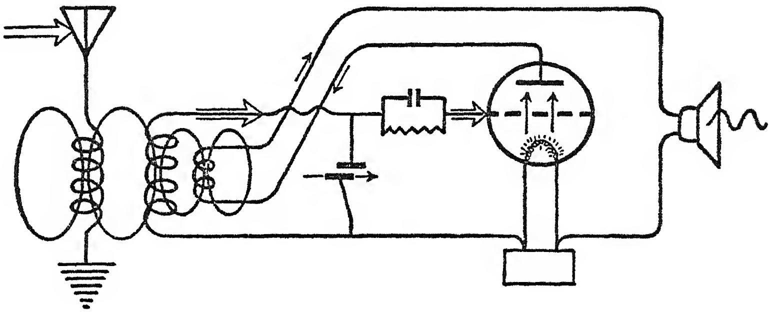
1883–1904: Thomas Edison, experimenting with his early incandescent lamp, stumbled on the basic principle of the electronic vacuum tube. Seeking to find out why filaments burned out, he inserted a metal plate in the lamp *(diagram upper left)*, connected it with a battery and discovered that a tiny but measurable current flowed across the empty gap from hot filament to plate. In 1904 Ambrose Fleming, an English physicist and consultant to Marconi, discovered that this tiny current, known as the Edison Effect, could be used to detect wireless signals. He curved Edison's plate into a cylinder around the filament and called the device a valve or, as it was later known, a diode. When the plate was coupled with an aerial, as shown in the circuit diagram above, it was rapidly alternated from positive to negative by the incoming waves, causing it alternately to attract and repel the tiny current from the filament, thus reproducing the signals in direct current to the headphones. But the Fleming valve, like the crystal detector, had no means of amplifying these signals.

DE FOREST AUDION OR TRIODE



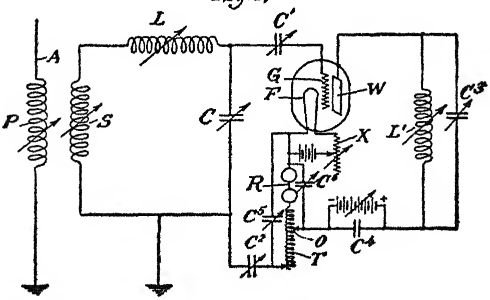
1906: The American inventor Lee de Forest added a third and controlling element to the Edison-Fleming vacuum tube device—a spiral wire or grid placed between the filament and plate, as illustrated above. This was called an Audion tube or triode. When the tube's grid was coupled to an aerial, as in the circuit diagram at right, the grid acted as a control shutter under the alternating positive-negative charges of the incoming waves, alternately passing and shutting off the current flowing from filament to plate to produce a replica of the incoming signals in the plate-to-headphone circuit. In some way this slightly strengthened the signals, but the triode's action was so little understood that initially it was little used.

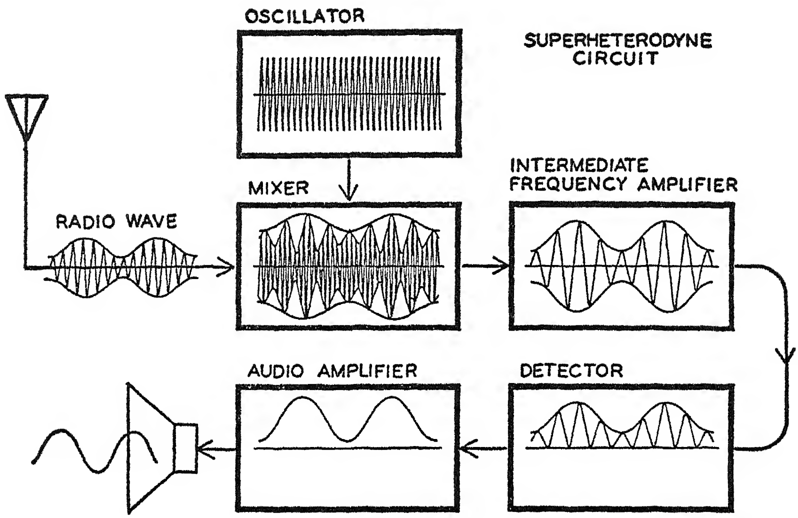
REGENERATIVE CIRCUIT



1912: Edwin Howard Armstrong, an undergraduate at Columbia University in New York, invented the regenerative or feedback circuit, diagramed above, in which de Forest's tube was suddenly revealed as a powerful amplifier as well as generator of electromagnetic waves. Closely studying the tube's action, Armstrong discovered that if part of the plate's output current was fed back and tuned into the grid *(arrow-marked loop at top of diagram)*, it reinforced and built up the strength of incoming signals to the grid as much as a thousand times. He also discovered that when the feedback was adjusted beyond this point of maximum amplification, the tube suddenly changed from a receiver to a transmitter, rapidly oscillating the current from filament to plate to send out electromagnetic waves of its own. With this dual-purpose circuit, still the basis of all radio transmitters, modern radio was born. The historic patent diagram is shown below.

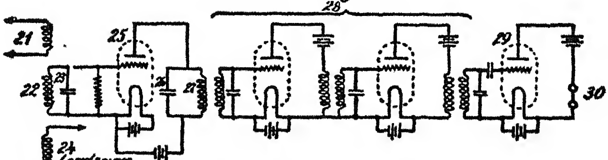
Fig.1,

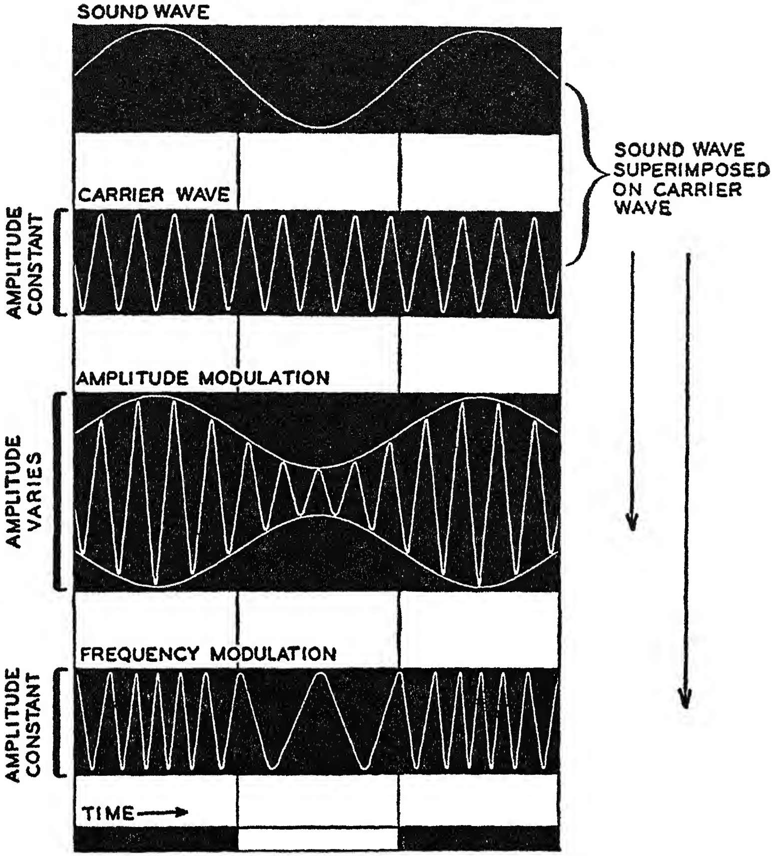




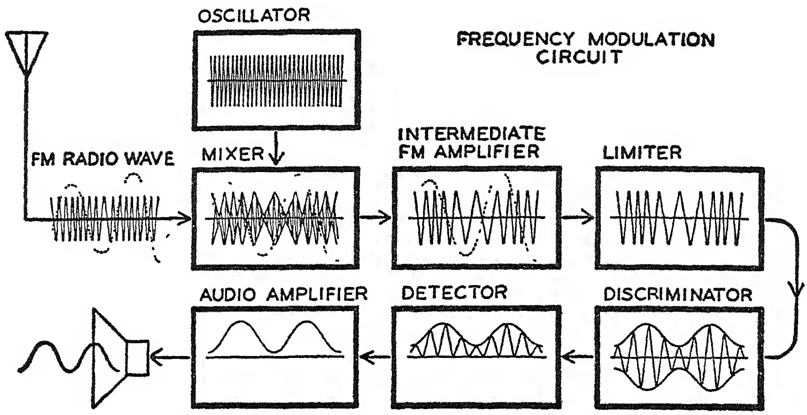
1918: Armstrong invented a second radio receiver, the superheterodyne, while serving as Major in the U.S Army Signal Corps in France. Designed to get much greater amplification of weak signals than was possible with the regenerative circuit, the superheterodyne operates as shown in the block diagram above, each block representing a stage of one or more vacuum tubes. Stage 1: the incoming signal wave is mixed or heterodyned with a wave of slightly different frequency from a local oscillator tube, producing a signal wave of intermediate frequency equal to the *difference* in frequency between the two mixed waves. Stage 2: the wave of intermediate frequency is amplified three or four thousand times. Stage 3: the amplified wave is detected and converted to direct current by lopping off the lower or negative part of the wave. Stage 4: The detected wave is amplified into the audio frequencies and converted at the loudspeaker into sound waves. Highly stable and selective, the superheterodyne is the basis of nearly all present radios.

Fig. 3,

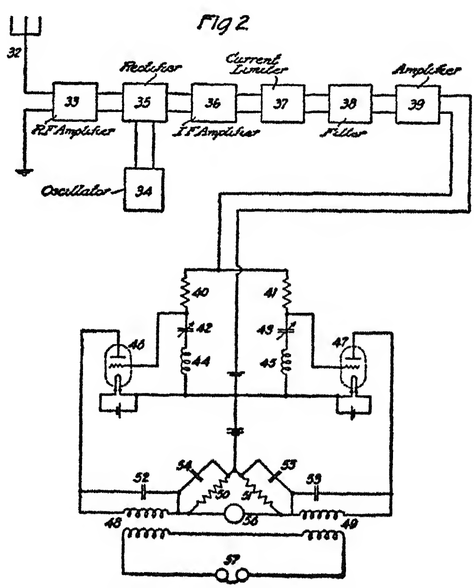




RADIO WAVES: Up to 1933, all radio waves were of the character shown in the top three strips of the diagram above. A sound wave was superimposed on a station's carrier wave by varying or modulating the carrier wave's power or amplitude (the up-and-down swings of the wave), thus molding the carrier into an exact replica of the sound wave's undulations. This is known as amplitude modulation. In 1933 Armstrong found a way to use an entirely different form of modulation. Instead of varying the carrier wave's amplitude, he varied only its frequency (the number of waves in a time interval) to produce the form of frequency-modulated wave shown in the bottom strip.



1933: Armstrong invented the frequency modulation or FM system at the end of a twenty-year search for a means to eliminate static. Most static is an amplitude phenomenon, mixing inextricably in the amplitude-modulated waves of ordinary radio. He therefore devised an entirely different radio system in which FM waves, modulated over a wide band of frequencies, are sent out and received by sets responding only to frequency variations. Key to the system is the receiver circuit shown in block diagram above, which is in all respects a superheterodyne except for the two additional stages labeled Limiter and Discriminator. The FM wave, with some static acquired in transit *(dotted lines)*, is heterodyned and amplified in the first two stages. Then the limiter clips off any amplitude variations (static) and passes on the clean FM wave to the discriminator, which converts its frequency variations into amplitude variations for detection and amplification into sound at the loudspeaker. The result is a nearly static-free, high-fidelity radio system, still the last word in radio development.



fied signal would finally be detected and converted to direct current. In the last stage this current would be amplified still further to actuate headphones or loudspeaker. In this ingenious roundabout way, the new receiver was made to take in weak signals of almost any high frequency, beat them down to a pre-selected intermediate frequency and then amplify them to a level never heard before. The whole circuit arrangement was properly called the superheterodyne.

This piece of legerdemain, which now underlies ninety-eight per cent of all radio receivers, embodies a large part of the essential, if oftentimes tarnished, magic of radio. The waves radiating out on all sides from a broadcasting station carry the soundwave pattern of speech or music as variations in the carrier wave's amplitude or power. This is called an amplitude modulated wave; i.e., vibrations from the microphone modulate the outgoing carrier wave's power up and down according to the tones being transmitted, while the wave's frequency remains constant. The modulated wave impinges on a house aerial and is drawn down into the receiver. There the tuned-in wave is successively beaten down in frequency, amplified in power, sheared in half to form a direct current, all the while that its soundwave pattern is carefully preserved, and finally reconstituted as sound vibrations on the diaphragms of headphones or loudspeaker in almost the exact timbre and tones of the original. All this happens, of course, in a fraction of a second from transmitter to receiver, far outrivaling in speed that fairy of a midsummer-night's dream who put a girdle round about the earth in forty minutes.

The superheterodyne circuit became one of the most enduring concepts in all radio because it met, with great sophistication, economy and cunning, so many of radio's basic needs. It provided, first, a means of receiving a very wide range of frequencies from the lowest to the highest. It provided a base from which these signals could be amplified to

almost any desired level. It allowed amplification to a point where headphones could be discarded for a loudspeaker. And the fact that it achieved this amplification at a fixed intermediate frequency made it highly stable and capable of being finely tuned to separate stations without interference, a feature that became of paramount importance as the number of stations grew. The superheterodyne became the basis upon which Armstrong later built his superior FM or frequency modulation receivers. And in World War II the superheterodyne, which had been designed twenty years before to detect enemy aircraft by their ignition radiations, was put to work as one of the basic receivers in microwave radar, a different and more practical method for aircraft detection. The superheterodyne was that kind of fundamental contribution to electronics.

In 1919, however, when Armstrong returned to the States, the modern radio industry as we know it was not yet born, the superheterodyne was not yet developed to a degree where it was a commercially practicable receiver and the whole stage of wireless was in the midst of scene-shifting. It was the great year of transition. Armstrong himself, as the year waned, was busy picking up the threads of his work with Pupin at Columbia and even busier directing the fight against de Forest in the interference suit over the oscillating feedback patent in Washington. Yet he did not neglect the development of the superheterodyne.

Harry Houck, his sergeant in France, was waiting for him in New York on his return, having decided to forego any visit to New Cumberland in view of this greater excitement. Together they set about pushing the superheterodyne method of reception to the limit. With great care, they built an improved five-tube set, using the greatly improved high-vacuum tubes then coming along, which achieved amplifications of 5,000- to 10,000-fold. In Yonkers that winter reception of spark-signals from the West Coast and radiotelephone

signals from Navy craft in Southern waters was recorded from a three-foot loop aerial. The day of the immensely long receiving antenna was nearly over, for the superheterodyne's ability to boost weak signals to unheard of levels made it unnecessary to gather every possible bit of radiation from the air. News of his latest feat had preceded Armstrong to the States, and later that year he delivered a paper on the superheterodyne before the Radio Club of America, which officially launched the new circuit on the radio world.

Some four years of development were still ahead, however, before the superheterodyne would be ready for general use. It was a much more complicated circuit than the regenerative and in its original experimental form difficult to adjust, particularly for novices. The first circuit stage had to be accurately manipulated to feed the proper intermediate frequency to the fixed amplifier, and the number of adjusting and tuning knobs was excessive. The first task, therefore, was to reduce the many knobs to two. Then the circuit had to be condensed and further simplified, making tubes do a double duty instead of one, in order to bring the set within range of economic manufacture. Houck carried on this later development alone and was given full credit for it. He shared with Armstrong an important improvement patent on the superheterodyne which covered a method for greatly simplifying the tuning of the set to the proper intermediate frequency.

Meanwhile, the superheterodyne, like the feedback circuit before it, was not destined to escape entirely the jealous claims of others. Indeed, no sooner was it disclosed than a cloud of claimants arose. As one veteran of those days recalls, a seemingly endless parade of characters came forward who had "worked with Armstrong in France" and who claimed that the superheterodyne principle had been appropriated from them. More serious claimants also arose with systems somewhat, if only vaguely, resembling Armstrong's. These

included Lieutenant Lucien Levy of the French Army, Walter Schottky of Germany and Lloyd Espenschied of the American Telephone & Telegraph Company. The most curious of these claims was that of Lieutenant Levy, whom Armstrong had met casually in France. Levy had devised an experimental system in which two waves of slightly different frequency were generated from the transmitter and then separately detected, mixed and amplified in the receiver, a system practically unworkable in its separation of functions and one that offered no solution to the problem of detecting weak enemy signals.

The validity of later claims that Levy's system covered the superheterodyne may be judged by the fact that the French government, which honored Armstrong for the invention and granted him a French patent on it, never allowed Levy's claims. None of the other rival systems came any closer to success, each of them lacking one or another important ingredient or sequence of ingredients to make them true superheterodynes. Nevertheless, such devices were sufficient, with a juggling of patent claims, to start interference proceedings in this country. Right after the war A.T. & T. acquired the Levy system, broadened its claims to embrace the superheterodyne principle and proceeded to put it in interference with Armstrong's patent in the U.S. Patent Office. These proceedings went on for some time and by sheer legal attrition began to weaken Armstrong's patent. But, as will be seen later, Armstrong was never seriously to be challenged as the true inventor of the superheterodyne.

Meanwhile, some even more curious maneuvers were going on in Washington that reveal the shifting and tortuous struggle for power in wireless communications at that time. The Navy, which was among the earliest developers of wireless telegraphy because of its technical interest in ship communications, was busily trying to get U.S. wireless practice out from under the basic patent structure of the vacuum tube.

It had a strong antipathy for British Marconi, which had refused to supply equipment except on a rental basis, and which still controlled, through the Fleming valve, the vacuum tube. The Navy claimed that the government's use of the three-electrode tube as regenerative oscillator and heterodyne was based not on de Forest, who had been an early and favored Navy contractor, nor on Armstrong of the Army Signal Corps, nor on any other inventor remotely connected with the device, but upon an entirely different and earlier inventor named Frederick K. Vreeland, whom it now put forward. A government review board investigated the claim.

Vreeland was a graduate of Columbia University a decade before Armstrong, a star pupil of Pupin's, a former assistant to Fessenden and an inventor of some note. He had, in fact, been one of the first to suggest the possibility of feedback in wireless, embodied in two patents issued in 1906. But his patents described a circuit using mercury-vapor tubes with outside magnets as control devices—something quite different from the electron tube—and only a passing reference to vacuum tubes, whose use he neither explained nor developed, gave any substance to the Navy's claim. An inventor to be credited with an invention must not merely disclose something new, he must also explain exactly how it may be usefully employed in a way reproducible by anyone in the art. So far as Vreeland's patents went, they described a device that, because of the sluggish movement of mercury-vapor currents, was incapable of oscillating at radio frequencies. If they disclosed anything more, it was the fact that the feedback principle in itself was not new. It was to be the basis of something new only when Armstrong later employed it in a vacuum-tube regenerative circuit for radio purposes. Vreeland himself had made no claims that he had done this. The review board therefore was forced to throw out the Navy's claim as irrelevant.

The Navy was much more successful in achieving its ends

in another and wider maneuver, started about the same time. In fact, this naval engagement was to lead late in 1919 to the formation of the U.S. radio industry. Armstrong had received news while he was still in France of a giant consolidation of commercial interests and had written in reply: "I have expected it for a long time and was prepared a year ago to take advantage of it when it came." Little did he know then of the massive and intricate convolutions of the modern industrial state, or of the monopolistic situations created when, in the national or public interest, government and industry awkwardly join forces to create some new instrument of power.

The formation of an industry rarely bears any resemblance to the enterprising legend later built up in the popular mind. The formation of the radio industry in 1919 resembled nothing so much as an uneasy consolidation of Balkan States. The government, and particularly the Navy Department, was increasingly concerned at the end of the war over the fact that all wireless communications out of the country were more strongly dominated than ever by a foreign concern, British Marconi. When the Navy's Admiral William H. G. Bullard heard that British Marconi was attempting to buy wireless generating equipment from General Electric on an exclusive basis, he set about through all channels to urge General Electric to buy out British Marconi's U.S. subsidiary, American Marconi, and reorganize it into an all-American company. General Electric's Chairman Owen D. Young accepted the task with alacrity and with great skill began a series of intricate negotiations.

In these negotiations the largest single satrapy in the communications field, American Telephone & Telegraph, could not be ignored. A.T. & T. had vital interests in radiotelephony and many patents, including, of course, all the relevant de Forest patents, issued or pending, on which the company was prepared to make a stand. It had done much

secret experimental work for the Navy, exploring transmission in the region of 1,000,000 cycles, the range of frequencies that were later to prove most useful for radio. Moreover, its great laboratories had made a host of improvements in the vacuum tube and associated equipment. General Electric, on its side, had a number of improvements and developments, including the Alexanderson high-frequency alternator which, though high-power vacuum tubes were coming along, was still regarded as the firmest source of wireless oscillations. With the purchase of American Marconi, further agreements could be reached under the key Marconi patents. Marconi himself was then pressing exploration of the shortwaves and was soon to make the discovery that these waves, contrary to belief, were the most potent for all long-range communications.

Thus it was thought that an agreement between these industrial states would pull together all important techniques and put an end to the patent conflicts that blocked swift development of wireless. During the war the government had discovered that no wireless equipment could be put together without inviting endless postwar claims, counterclaims and suits. Well over 2,000 patents had grown up in the wireless art, many of a minor or merely nuisance value. The patent system, in its august protection, did not distinguish between true invention and minor improvement of detail. The consolidation of all the dispersed patents in wireless was only second in the government's view to getting rid of foreign domination in the field.

Nowhere, however, in all the sections, articles, clauses, codicils and cross-licensing arrangements of the elaborate Agreement that was finally drawn up by the negotiating corporations was there any provision for radio broadcasting as it was soon to develop. It was not even remotely contemplated. All that was arranged for was an extension of wireless services as they had been known, for the assembled

dignitaries could not see any way to make money except in point-to-point communications for which tolls could be charged. The idea of spraying the air with "free" music, instruction and entertainment occurred to no one. No one, that is, except American Marconi's young assistant engineer and by then commercial manager, David Sarnoff, who in 1916 and again in 1920 wrote two important memoranda, promptly turned down but destined to become the vehicles by which he later rose to power, urging his company to get into the sale of what he called radio "music boxes."

To be sure, others had had this vision long before Sarnoff. As early as 1904, Nikola Tesla, the original inventor of the high-frequency alternator, had prophetically foreseen the destiny of radio. "I have no doubt," he wrote, "that it will prove very efficient in enlightening the masses . . . It involves the employment of a number of plants, all of which are capable of transmitting individualized signals to the uttermost confines of the earth . . . A cheap and simple device, which might be carried in one's pocket, may then be set up somewhere on sea or land, and it will record the world's news or such special messages as may be intended for it." And, of course, amateurs of all ranks had never ceased to press on in pursuit of this goal. But these inventors and amateurs were obviously visionaries and not the solid, practical men of affairs who now forgathered about the big mahogany conference tables to agree among themselves how the new wireless industry, as they saw it, was to be constituted and divided.

On November 20, 1919, General Electric completed the purchase of American Marconi from the British for something over $3,000,000 and transferred its assets in exchange for stock to the newly formed Radio Corporation of America. Ironically, for the first two years of its life this corporation was to have nothing to do with radio as we know it. A few months later A.T. & T. came into the circle with a purchase of R.C.A. stock for $2,500,000. Everything was, or

so it was thought, tidily arranged. All patents of the participating companies were to be freely available to one another for ten years. A.T. & T. was to have roughly as its exclusive field all radiotelephony associated with its telephone service, plus the manufacture of transmitter apparatus. G.E. was to have roughly all wireless telegraphy and the manufacture of receiver apparatus. R.C.A., with no manufacturing rights, was to operate the transatlantic service of the old Marconi Company and act solely as a sales and service organization for the group. Patent agreements were concluded through R.C.A. with the British, French and Germans to make the arrangement international in scope.

Thus was the stage set for the almost spontaneous and unforeseen explosion of radio broadcasting in the Twenties. The Radio Corporation of America was born as a quasi-governmental instrument of national policy. Into its hands was put, by cross-licensing agreement, the administration of all important wireless patents as they applied to radio use, eventually giving this one company enormous power and control over the new industry. Perhaps there was no other way in a laissez-faire economy to create the industry, for the commercial development of electronics was to require the concentration and engagement, by one means or another, of very large technical and financial forces. In a rough and ready way the Agreement of 1919 created the largest and most vigorous industry of its kind in the world. But a high price was to be paid in chaos and in abuse of power for lack of sufficient government foresight and control. More than a quarter of a century later the government would still be trying to undo some of the more baleful consequences of the 1919 Agreement.

Against this large backdrop of governmental and industrial maneuver, Howard Armstrong was a single figure barely discernible as the country moved into the Twenties. He held two of the most vital inventions in radio, but he was

largely ignored by the negotiators, and it is doubtful whether even he realized the important role that the superheterodyne was to play in the development of radio. Except for his old license on the regenerative circuit with American Marconi, which continued to pay him some $3,000 in 1919, he had almost no connection with these world-shaping events. But his involvement was not to be long delayed.

Chapter 9

Young Man of the Twenties

THE TWENTIES OPENED with a flourish of jazz trumpets. Everywhere the tempo of things rose to a syncopated beat. Armstrong's life in the first years of this memorable decade whirled up with the times in a mixture of themes difficult to follow. In quick order he slipped back into his laboratory work with Pupin; sold his first two inventions for a large sum; fought and won a resounding legal victory over de Forest in a high federal court; in the course of this suit came up with a third invention, which he promptly sold for a sum even larger than the first; and continued on with the investigations to eliminate static which he had begun with Pupin in that now faraway world before the First World War.

Suddenly, too, on the first high and swift wave of success, Howard Armstrong fell in love and belatedly discovered his youth. He had been gripped since high school in the cage of his genius. No sooner had he worked out the first of his inventions than the war had swallowed him up and impelled him toward another. Now, after labors, trials and achievements that few men by the age of thirty manage to encompass, he was suddenly moving in the changed, exhilarating air of the Twenties, an exciting time in which to be still young and talented and alive.

Indeed, in those first years after the war, it seemed that both the country and the century were belatedly discovering their youth. An ardent, febrile, romantic, high-strung, hell-raising generation came to the fore, in gaudy revolt from the

solemn absurdities of the late Victorian world. Its elders, who still ruled and who already were launched upon another noble and disastrous experiment known as Prohibition, looked on with dismay or with simple, graven hypocrisy. The hip-flask, the cocktail party, the bobbed-hair coiffure, the Stutz Bearcat, the swooping cloche, the corsetless sack, the fox-trot became the defiant symbols of the new generation. And swelling up through it all was the new jazz music, soon to be caught up on the airwaves and destined to impress its name and rhythm on the age. The elders retired again into splendid isolation, behind McKinley tariff walls even higher than before, but the younger generation which had tasted some of the fruits of Paris went back for more. For the first time in the country's history, part of a whole generation came to be called expatriate, no longer pledging allegiance to the prevailing mores, ready to question the wisdom and values of an acquisitive society building up ever more suffocatingly since the Civil War. A few shabby radicals were jailed by the ineffable A. Mitchell Palmer for daring to suggest that there was something wrong with this civilization and that the war had been fought in vain—truths that everyone below a certain age was to come bitterly to know. But for the younger generation the world was still ruled by the Stuffed Shirt, and it was all too ridiculous. The main revolt, therefore, was native, random and, on the whole, non-political and aimless. The new generation's mad exploits and high animal spirits were soon being played up in the newspapers and mirrored with great flawed beauty in the novels of F. Scott Fitzgerald. Other and greater voices—Lewis, Anderson, Dreiser, Mencken, Hemingway and, finally, Faulkner—found outlets in satire, lambasting criticism and novels of a new realism and limpid honesty. Suddenly, with a loosening of the leaden hand of commercialism and middleclass mores, a spout of clear creativity burst upon the land, such as had not been seen since the early, transcendental years of the previ-

ous century. In its unleashed vitality, this new generation created the style, set the tone, wrote the songs, composed the plays and conceived the poems that are still heard freshly, thirty years after the event, as the living accents of this century.

There was an elixir in the air. New York, after France and the test of war, had, in the words of Scott Fitzgerald, all the iridescence of the beginning of the world. Its glacier-white towers and sparkling air gave off a new and crystal smartness, an excitement, that made it seem the very center of a new world. And dimly in basements all over town the speakeasies were opening to add a fillip of forbidden pleasure to the electric atmosphere. Armstrong had all the suddenly sharpened sensitivity of his romantic generation for time and place. Beneath its capers and its revolt and its sardonic criticism of society, the new generation, even that part of it called expatriate, was drawing portraits of New York and Chicago, Gopher Prairie, Minnesota, and Winesburg, Ohio, more lovingly and bitingly realized than any portraits of America before or since. So to Armstrong in those years, the look of the Hudson River, the narrow canyons of lower New York, the red-brick rectangle of Philosophy Hall with its brooding cast of Rodin's Thinker on a pedestal before it, and a hundred other Manhattan sights and sounds became indissolubly woven with the quest and promise of his youth.

Armstrong, working strictly in the sciences, shared the great creativity of the era and more than a touch of its madness. Within the wireless fraternity, he was indisputably the man of the hour. Immediately on his return to the States, the Radio Club of America, grown enormously since the close of the war, threw a memorable party in New York's old Hotel Ansonia on 78th Street, where the Junior Wireless Club had been organized ten years before, to honor its returning hero and president, Major Edwin H. Armstrong. To

his older intimates he would always remain "Howard," but to his new friends and acquaintances he would be known henceforth affectionately as "the Major," without military affectations. He even came to prefer this title to many a loftier one later conferred, and the press picked it up to associate it indelibly with his name. He was in rare form on that November evening in 1919. He had an easy, drawling manner of speech, which while conveying authority was still so modest as to engage the listeners in his exploits and draw them on as he painted the future of radio. His eager audience that night was composed of the veterans and the youths, their hair slickly parted down the center in the new fashion, who were to become the technicians of the broadcasting revolution, still only a barely audible murmur in the distance.

The Radio Club became the center of Armstrong's social activities in this period. To his earlier circle of Yonkers friends, Russell, Runyon and Styles—the latter forsaking wireless temporarily for a job with the Bankers Trust Company—he now added some of the club's founding members and leading spirits. These included George Burghard, John Grinan, Ernest Amy and John V. L. Hogan, the last a long-time associate of Fessenden's and a notable contributor to heterodyne reception. Burghard, in particular, became his closest friend and companion in this period and in the years thereafter. A New York boy of well-to-do parents, who had been one of the early wireless enthusiasts but who had graduated in law from Columbia University in 1918, Burghard was a gay, suave, outgoing young man with a large capacity for life, still intensely interested in radio. He was, in that time and place, the perfect foil for Armstrong, drawing him out of himself, helping him to know the world. Burghard had a flair for dress and conversation, a fast foreign car—a Delage—all of which Armstrong envied, and a devotion to Armstrong's genius that was to grow with the years. To-

gether, as the decade quickened, they heard many a chime at midnight.

Neither the gaiety nor the talk ever strayed very far from radio. Burghard would sometimes run out to 1032 Warburton to sit in on the innumerable tests and experiments, which rarely ended before the dawn crept golden down the Palisades on the western shore. More often Howard, after his work at Columbia or long sessions with his lawyers, with whom he was increasingly busy in the de Forest matter, would drop in at Burghard's place, then at 93rd Street and Fifth Avenue, the family residence, later in bachelor quarters at 500 West End Avenue, where the Radio Club's directors also met. Armstrong invariably tried to make the last train back to Yonkers, and invariably missed it. An hour before train time he would begin reminding himself, then get absorbed in discussion and overshoot it, finally make a dash when it was plainly hopeless, and dodge into the Hotel Ashton down the block to take a room for the night. He was too diffident to put anyone out about his sleeping arrangements, though he was always warmly urged to stay the night. Once he forgot his diffidence. Burghard had built a fancy, fifteen-tube transatlantic longwave receiver, with expensive Weston meters between each stage to observe its operations. It wasn't working properly. To get Howard around to applying his magic touch, George plied him with sweet muscatel, at that time one of Howard's favorite, unsophisticated drinks. When he finally ambled over to the set, he made one shift in wiring and blew out all the meters. "M'boy," he said, owlishly horrified at the enormity of his deed, "we'd better go to bed."

Wherever the meetings took place, it was talk, talk, talk, endless and winding, of tennis, which he again was playing, of racing cars, which he hoped to own some day, of mountain climbing, a subject in which he was an avid reader of all the literature in lieu of any mountains to practice on, until fi-

nally the conversation would circle around to the radio matters then engaging his interest. As other young men even then were talking endlessly in close rooms, bars and foreign bistros of the great American novel or the theory of poetry or the founding of mercurial new magazines, fertilizing their dreams with talk, so this group was absorbed in the shining prospects of radio.

Late in 1920 Armstrong's affairs came to a sudden boil, after having simmered for months and years. Early in the fall he received a telephone call from William Davis, his lawyer, telling him that a large offer had been made for the purchase of his inventions. The offer came not from any of the companies he had had any dealings with but from the Westinghouse Electric & Manufacturing Company of Pittsburgh, developer of the alternating-current principle in U.S. power transmission and second only to General Electric in size. Westinghouse had been left out of the big wireless industry Agreement reached in 1919 because it had only begun to experiment with wireless just before the war, but Westinghouse was determined not to be left behind in whatever was developing. In fact, it was prepared to play a very fast pick-up game with large stakes. It already had purchased a large interest in a company founded on Fessenden's inventions, gaining control of important patents on continuous-wave transmission and heterodyne reception. It now shrewdly saw that young Armstrong held the key patents in the use of the vacuum tube, which had been ignored by the other companies in their absorption with their own patent positions and the building of empire. Westinghouse quietly set out to acquire these patents for any price within reason. Some wind of this reached General Electric, for it belatedly began to make moves in the same direction. But its chief counsel was out of town when the Westinghouse bid came into Davis' office, and Davis strongly urged Armstrong not to

wait for a G.E. bid, lest the two giants be given time to get together and beat down the price.

On October 5, 1920, therefore, Armstrong swiftly signed over both his feedback and superheterodyne patents to Westinghouse for $335,000, payable over ten years. An additional $200,000 was to be paid when and if his feedback oscillator patent, still held up in interference proceedings with de Forest, was issued. Armstrong was moved to this swift sale by the simple fact that, with only his small university salary and minute licensing fees to go on, he was increasingly strapped to meet lawyers' bills. He was already $40,000 in debt to Pennie, Davis, Marvin and Edmonds, and he had accepted a $5,000 loan from one of Pupin's wealthy backers to tide him over a tight spot. To have attempted to hold on to his own patents in an industry in which the tangle of patent suits already had reached a point of strangulation would have been to court death by litigation. He had enough unavoidable litigation ahead without asking for more. His career since the end of the war had been a rapid, daring skating over thin ice. With the new funds he was able to pay off his debts in full and gird himself for more untrammeled research and a frontal attack on the de Forest situation. He also managed to include in the sale some lesser patents of Pupin's, which enabled him proudly to turn over to Pupin some $20,000. Out of it all he also managed to retain, as de Forest had retained, rights to his patents for experimental and amateur use, rights which the big companies still regarded as of no commercial importance.

Meanwhile, however, the amateurs had been rising in numbers exceeding anything seen before, swelled by the ranks of returning veterans from the A.E.F. Signal Corps and Navy communications. Like a wind in the wheat, like a prairie fire, fed by the gusty passion of American youth for mechanical things, the radio broadcasting revolution rolled up from 1919 on from dozens of amateur stations. De Forest

reopened his experimental New York station, closed by the war, and again began playing gramophone records, interspersed now with whatever free talent he could inveigle from Broadway, starting with the singer Vaughn de Leath. This station was cut off the air for lacking a proper license and for interfering with Navy messages—"there's no room in the ether for entertainment" said an irate official—but de Forest went to the West Coast and opened another station and sold a transmitter to the *Detroit Daily News*. In August, 1920, this was the world's first commercial radio station regularly on the air.

Electrical supply stores suddenly began doing an avalanching business in receiver parts. Amateurs began building radio sets for neighbors and other amateurs. Supply stores and hastily organized small companies began putting together units of their own for sale. Soon the term "amateur" covered nearly everyone in the country. Thus in a special and poignant sense it was not any superior vision lodged in the executive heads of the leading corporations of the time but the people themselves who created the radio broadcasting industry, carelessly, off-handedly, hardly aware of or long remembering their own galvanic power. By 1922 the craze for listening-in—to no matter what—joined the short skirt and bobbed hair as a phenomenon of the era.

Early in 1920 Armstrong's lawyers had seen this rising business, still mostly in crystal-detector sets, and, seeking to raise his income, had guided him into licensing his regenerative circuit for amateur use. This was Armstrong's first experience in managing his patents on any scale. He kept his own account book on royalties collected, a small gray ledger innocent of double-entry bookkeeping and written in a still boyish hand. The first entry ran: "Clapp-Eastham Co. Date of license—April 28, 1920. April 1-June 30, 1920—$12.60. July 1-Sept. 30, 1920—$5.06." Through other entries run the names of small and long-forgotten enterprises that built

some of the first radio sets: A. H. Grebe & Co., Tri-City Electric Supply Co., Chicago Radio Laboratories, Inc., Cutting & Washington Radio Corp., Klitzen Radio Manufacturing Co. By 1922, still retaining his licensing rights for amateur use, Armstrong had twenty-four such licensees and his royalties rose perpendicularly to some $10,000 a month. Royalties might have been much more if he could have kept up with everyone employing his feedback circuit.

This was precisely the situation which the big-company Agreement of 1919-1920 was totally unprepared for. A.T. & T.'s engineers had done some solid experimental work on broadcasting, but no one higher up thought it was a business. Westinghouse, more aggressive, put an experimental station on the air just in time to report the election of President Warren Gamaliel Harding and the great Return to Normalcy in November, 1920, and to make a flurry of headlines as the "first" broadcasting station. But Westinghouse was taken into the Big Radio Group in June, 1921—to avoid "cut-throat" competition—with no basic changes in the underlying Agreement, which still looked only to a tidy business in radiotelephone and international radio communications. The only change was that Westinghouse was now given exactly 40 per cent of the manufacture of whatever radio receiver equipment the Radio Corporation of America sold, while G.E. retained 60 per cent, and A.T. & T. continued to make transmitters and all equipment for its own and telephone uses.

When the "amateur" explosion finally penetrated to the thick-carpeted board rooms late in 1921, and R.C.A.'s Sarnoff, by then general manager, finally made his voice heard, the situation was completely out of hand. Armstrong's amateur licensees were running wild and de Forest's company was beginning to make audions hand-over-fist. By the end of 1922 there were nearly 300 set manufacturers, paying little or no attention to R.C.A.'s carefully erected patent structure.

Within two years over 500 broadcasting stations were on the air, paying no attention to A.T. & T.'s claim that it was supposed to be the only builder of transmitters. A raggle-taggle mob of free enterprisers was running away with the business.

The incredible Agreement began to burst here and there at the seams. The members began fighting among themselves. Westinghouse, having established Station KDKA in Pittsburgh, leaped into the fray to build, jointly with R.C.A., Station WJZ in Newark in mid-1922. A.T. & T. countered by building Station WEAF in New York and set out to get all broadcasting, plus all tube and transmitter manufacture, back under its control through its de Forest and telephone patents. It disposed of all its R.C.A. stock. It attempted, because of its belief that charging for domestic "messages" was a Telephone Company prerogative, to prevent all broadcasters but itself from selling time on the air. It attempted to withhold—after initiating the first network broadcast via telephone line between WEAF and Boston in 1923—all telephone lines from stations that did not take licenses under its patents. It also tried to enjoin G.E. from selling transmitters, and it attacked G.E.'s Langmuir patent on the high-vacuum tube with a patent of its own, both patents being later thrown out by the Supreme Court as involving no true invention. (Actually, Langmuir's basic work on the high-vacuum tube and high electron emitters constituted one of the really important inventions in radio development.) In turn, G.E., Westinghouse and R.C.A. charged the Telephone Company with breaking the Agreement by entering broadcasting. Later A.T. & T., after a public outcry over its attempts to monopolize radio as well as telephony, completely withdrew. Finally, the members of this historic Balkan entente were attacking one another for violating, of all things, the anti-trust laws.

R.C.A., meanwhile, was unable to get a single radio set to

sell until 1923, and then only a crystal set trademarked the Radiola I. R.C.A. was tied to the ponderous, slow-moving manufacturing arrangement with G.E. and Westinghouse, which for ten years was to prevent it from making any sets of its own. Indeed, R.C.A. was to spend most of the decade merely trying to catch up and to recapture the situation. New and faster-moving companies, such as Atwater-Kent, Grigsby-Grunow, Crosley, Philco, Zenith and Emerson, got most of the business. Thus, as a kind of pinnacle to this "era of wonderful nonsense," the company that had been set up almost by government ukase as the premier Radio Corporation of America was neither the first to broadcast nor the first to sell radios nor the first in anything. It innovated not, neither did it spin. Yet it eventually proceeded, by a topsy-turvy turning of capitalism on its head, to control and exact tribute from the whole radio industry. It proceeded, by reason of the cross-licensing features of the Agreement that continued in effect through all the bickering, to use the 4,000 or more patents at its disposal, now including the main Armstrong patents, to whip competitors into line by punitive suits, restrictive licenses and forced royalty payments. In this there was no nonsense but a ruthless wielding of the immense power given it by the brief collaboration of military and industrial interests back in 1919.

To top all this, late in 1921 the veteran radio amateurs stole another march on the communications industry by being the first to send a shortwave message across the Atlantic. This was an exploit in the defiant spirit of the times, and Armstrong played a leading role in it. It came about through the fact that at the end of the war military and commercial interests had finally managed to get the amateurs restricted by government order to the spectrum of frequencies above 1.5 megacycles, or a wavelength of 200 meters. Up in these "commercially useless" shortwaves, it was thought, the amateurs would be out of everyone's hair. After some initial

grumbling, dyed-in-the-wool amateurs became so fascinated by this new region that they gave less and less attention to the longwaves, now beginning to be crowded with broadcast "junk." For, as they explored the supposedly barren shortwaves, trying to build up transmitter power and to get distance in them, the feeling grew that these shortwaves would travel much further than anyone supposed. Theory held that the weak shortwaves were only good for very short distances. No one, however, had had the gumption to put theory to the test.

Late in the summer of 1921, *QST*, the magazine of the American Radio Relay League and the bible of all amateurs, proposed a massive test in cooperation with British amateurs. For ten consecutive nights in December a group of leading U.S. amateur stations, transmitting on a strict schedule, would attempt to get a shortwave message across the Atlantic. To insure the test, *QST* decided to send an American with U.S. receiving equipment to the other side to set up an around-the-clock listening post. The man selected for the job was Paul F. Godley of Montclair, New Jersey, a member of the Radio Club, widely known in amateur circles as "Paragon Paul." Just before sailing alone on the old *Aquitania* for England in mid-November, carrying a superheterodyne receiver, Paul implored his Radio Club well-wishers to build a station that would get across. He was afraid that none of the amateur stations had power enough to make it.

With only three weeks to go before the test, the Radio Club's leaders decided to build a special station for this purpose. Selecting as site a member's station near Greenwich, Connecticut—Station 1BCG owned by Minton P. Cronkhite —the quintuplet of Armstrong, Burghard, John Grinan, Ernest Amy and Walter Inman piled high with equipment an old Packard car that Armstrong had acquired earlier in the year and proceeded to slide out on the icy roads to Green-

wich. There, in a snowstorm, working practically night and day, they moved Cronkhite's radio shack out into an open field, erected a 100-foot cage antenna and installed a 1,000-watt transmitter, which, to save time, was of the A.C. self-rectifying type, transmitting on 230 meters. This apparatus didn't work to Armstrong's satisfaction, and with only three days to go he suggested that they rebuild it into a master oscillator power amplifier of the D.C. type, such as he had introduced so successfully in the A.E.F. network. The shack had to be moved again closer to the antenna, more parts snaggled from the Columbia laboratories, and two big D.C. motor generators moved in from Stamford to supply the power.

On the first night of the tests all was still chaos at 1BCG, and, through one mix-up or another, it was not until the third night that operations were in order. Everyone took ten-minute turns at the key, for telegraphic code was all that could then be attempted and the cold was so numbing that operators quickly developed "glass arms." The chief operator was Johnny Grinan or "JG," who had what was known as "one of the prettiest fists in radio," recognizable in its clear and distinctive style by amateurs from coast to coast. On the third night George Burghard was at the key when, as was learned twenty-four hours later, his call letters got through to Godley, listening alone in a tent on a galeswept beachhead at Ardrossan, Scotland. By arrangement with British Marconi and R.C.A. engineers, Godley's reports were relayed back to the States in off-hours by regular longwave wireless, and now the report came winging back in telegraphic lingo: "Heard One Boy Cast George Calling Me Strong Steady Congratulations."

The following night 1BCG cleared all decks to send its message. Johnny Grinan sat beaming under a 120-watt lamp rigged up over the key to keep his hand warm, and promptly at 9:45 P.M. began sending out the message over and over again: "Nr. 1 de 1BCG words 12, New York Decem-

ber 11, 1921. To Paul Godley, Ardrossan, Scotland. Hearty Congratulations. Burghard, Inman, Grinan, Armstrong, Amy, Cronkhite." Not only did Godley confirm the full message by cable, but 1BCG, first among a hundred or more amateur stations competing, was heard over England, Holland and Germany, a distance of some 4,000 miles. It was a new sensation of the wireless world.

Amateurs jammed the ether calling 1BCG. The station wheeled around and conversed with "hams" as far west as Catalina Island, California. The small radio shack had an endless flow of visitors. Pupin came out in greatcoat and high derby to see what the boys were up to, and Sarnoff flanked by R.C.A. aides came out to see how the feat which had been pronounced impossible was accomplished. On about $1,000 worth of equipment, amateurs had done what the communications industry could have done much more easily, if it had had the initiative.

Still the U.S. industry was not to be stampeded into following up this promising new lead to shortwave transmission. In fact, it was not to be until 1927, long after Guglielmo Marconi, in the second of his great discoveries, demonstrated beyond doubt the superiority of shortwaves for all long-distance communications, that the U.S. industry began to move into this "commercially useless" band of frequencies. Marconi's discovery, made in 1924, was that shortwaves of 30 meters or less, much shorter than any used theretofore, could be heard round the world through daylight as well as dark. This marked the discovery of skywave transmission, an entirely different means of radio transmission from the groundwaves he had discovered twenty years before, and it marked the decline of the ultra-longwaves in international communications.

The U.S. communications industry, if the truth be known, had little time to consider shortwaves in 1922. It was too busy cashing in on the incalculable legacy left it by the

amateurs in the longwaves suitable for broadcasting. The cacophony of the radio boom was beyond anything known before or since. Stations went on the air all at much the same frequencies, and the din of interference was ear-splitting. The government was as unprepared for all this as the industry. Scientists and engineers were queer people whom the government called in in emergencies to pass a few "miracles," but no one would think of listening to all their crazy predictions or asking their advice on how to plan for the future. Hence the government had only an obsolete 1912 law, passed for the regulation of wireless telegraphy, to meet the new situation. Not until 1927 did Congress, chary of any regulation, though the industry by then was begging for it, pass an Act that brought some semblance of order.

Some stations tried to drown one another out. Morse-code messages, ship-to-shore radio and a few still rambunctious amateurs added to the unholy broadcast confusion. WEAF hired the first full-time radio announcer, Albert V. Llufrio, who also played the piano; WJZ countered with a young tenor named Milton J. Cross; WEAF came back with Graham McNamee, whose excited announcing of sports soon became one of the grating noises of the era. The two stations, both on the same wavelength, fought the shrill battle for dominance between the Telephone Company and R.C.A. It was still unclear how broadcasting could be made to pay, or if it should. Sarnoff proposed that all broadcasting be supported as a public service, free of advertising, solely by radio industry contributions, implying that there was something unclean in accepting advertising as A.T. & T. was beginning to do. But it was not long before all the airwaves were loud with the voice of the hucksters. Meanwhile the sale of radios covered nearly everything. The public appetite for sets was insatiable and not to be filled for years. Queues formed before stores that had any sets or parts. Dealers were a year catching up on orders. A crystal-detector sold for

as high as $25; a one-tube regenerative set with batteries came to about $80; and a three-tube detector and tuned circuit amplifier went for $250 and higher. The superheterodyne was not yet ready for production. Radio, like mah-jongg, cross-word puzzles, Couéism and flagpole-sitting, was wafted up on the faddish hot airs of the decade to unimaginable heights. In the generally booming economy, radio sales hit $60 million in 1922, more than doubled that in the next year and rose straight on up to nearly $900 million in 1929. An expatriate dialogue of the times ran like this:

"What news from New York?"
"Stocks go up. A baby murdered a gangster."
"Nothing more?"
"Nothing. Radios blare in the streets."

The man whose circuits were responsible for this metamorphosis of wireless into the booming blare of radio, at once as inexhaustibly vigorous and violent as the times, went quietly about his business between Yonkers and Columbia University, practically unknown to the public, rarely listening in to the blather, absorbed in his work and affairs. Almost as soon as his inventions were sold to Westinghouse late in 1920, Armstrong had buckled down to preparing a suit, backed by Westinghouse's legal department, against the De Forest Radio & Telegraph Company to assert the validity of his regenerative patent over de Forest's infringing claims. This suit came to trial in January, 1921, before Judge Julius Mayer in the U.S. Federal Court, Southern District of New York, and its dramatic details and final victory for Armstrong will be recounted later in a summation of all the de Forest litigation. Through 1921, however, and even through the transatlantic shortwave experiment, when the suit was rising to a climax, Armstrong spent long hours in preparation and longer hours in court, following every legal detail and rigging

up apparatus for courtroom demonstrations to prove his points. With Armstrong there were never any half-measures, and he set out to understand this new legal world as thoroughly, if possible, as he understood radio. Afternoons after court he would drop in at 16 Warren Street, close by the court house in lower Manhattan, where George Burghard and some of his radio associates had set up the Continental Radio Corporation, soon to be the first and biggest of R.C.A. distributors, there to chin over the day's court battle.

One night while setting up one of his original regenerative circuits in his Columbia laboratory for the purpose of taking it into court next day to refute an opposing lawyer's statement, Armstrong suddenly heard a signal coming in with a volume beyond anything to be expected from regeneration. He had only time to identify it as a message from the Brooklyn Navy Yard across the river, and to pull in other well-known stations at many times normal volume, when the effect disappeared. It was then 2 A.M. Dropping everything else, he went after this new phenomenon on all fours.

"Five minutes before," as he later ruefully described his sensations, "I would have sworn to the high heavens that I understood all there was to know about regeneration. Five minutes only were required to wipe out that complacent belief engendered by nearly a decade's work with the subject. Some completely bewildered experimentation eventually restored the strange effect, and finally I learned how it could be maintained long enough to examine it."

The strange effect was to be pinned down, after some weeks of exhaustive work, as the principle of superregeneration, an entirely new extension of the feedback principle. When this regenerative circuit was allowed to amplify beyond the well-known point where its audion tube became an oscillator or generator of radio waves, a second or "quenching" tube cut in to suppress the oscillations at the rate of 20,000 times a second, allowing amplification to build up in the intervals

to 100,000 times the original signal strength. This was far beyond the capabilities of even the superheterodyne circuit. Because the first tube was being cut off and on so rapidly in the inaudible high frequencies, the tones that finally emerged from headphone or loudspeaker sounded continuous and unimpaired to the human ear. Here was a means of getting beyond the oscillation barrier that limited the original feedback circuit as a receiver, a means which dozens of investigators had been hunting for ever since the first exposition of feedback in 1914. It came to Armstrong by one of those chance observations that are so deceptively simple-looking in the history of invention, since they mask the fact that the chance is worthless unless the right man is there to pick it up. The circuit in which Armstrong discovered the superregenerative effect had been one of those diagramed in his original feedback patent; literally hundreds of technicians had been working all around it since 1914; and Armstrong himself, as he was suddenly to recall many years later, had observed the effect in 1913, but so briefly and imperfectly that he passed right over it. Given a second chance, however, he did not miss.

The superregenerative discovery came at a time when the inventor not only was embroiled in his first big patent suit, but also was still in the midst of developing the superheterodyne circuit with Harry Houck and carrying forward his studies of static elimination with Pupin. Even Armstrong's prodigious capacity for work was hard-pressed to encompass all this, and his old amateur friends leaped in to assist him. Through the winter of 1921-1922 Randy Runyon helped him to put the superregenerative circuit through many tests. A loudspeaker horn was poked out of the attic window at 1032 Warburton. Runyon paced off one thousand feet and still he could hear the broadcast music pouring from the speaker. Even behind closed windows and doors it could be heard by residents a quarter of a mile away. The receiver was so pow-

erful that it did not even need an antenna. At the same time Bill Russell, who had helped Howard build antenna kites so many years before, followed through on circuit development, building the apparatus to explore the new circuit's action in many forms. Armstrong filed for a patent in 1921, which was issued as Patent No. 1,424,065 in July, 1922, and was quickly followed by six additional patents in the same area, all of which withstood the test of time.

Meanwhile, Houck had run into some trouble in the superheterodyne work. He brought the gear over to Armstrong in New York one day from his New Jersey workshop, where he had settled, married and set himself up in a small way in the new electronics business. "We'd better take this up to Yonkers," said Howard, after they had toiled over it for some hours without getting to the bottom of things. They caught a train to Yonkers, and Houck stayed on that night and the next, as Howard pursued the problem with that deep absorption into which he could plunge for hours and days, oblivious of all else, drawing everyone associated along with him. Meals in the Armstrong household had an invariable ritual, beginning about an hour beforehand when his mother would call up the stairs that dinner was just being put on the table, and rising in a crescendo of urgency to the statement that everything was now stone cold. "Guess it's about time to go down to dinner," Howard would placidly say, and arrive in the dining room just as the steaming plates were emerging from the kitchen. Late on the second day of Houck's stay the problem was run to earth and the set suddenly blared forth with a crisp report from the Missing Persons Bureau, an established feature on WJZ in those days of lean programing. Armstrong's hand promptly shot out to switch it off.

"Leave it on, Major," said Houck with dry Dutch humor, "I want to see if my name's on it. I've been missing for two days and my wife probably has the police on it by now."

Howard was swiftly all contrition, as he always was when he had so far forgotten the world as not to observe its amenities, and he telephoned to Houck's wife to apologize personally for keeping her husband away for so long.

Both the superheterodyne and superregenerative circuits were by then the hottest prospects on the radio horizon, though most engineers still believed that the "superhet" would never be sufficiently simplified for mass production. The superregenerative was the newest sensation. Moreover, it came at a time when the radio boom was just clearing the first peak and heading for the stratosphere, and people were eager to grasp the latest advances of the new wonder-workers of radio. Diagrams of the new circuit appeared on the radio pages of all newspapers, a new feature of the times, and neophytes who had barely digested the mysteries of regeneration were plunged into the arcana of superregeneration. It was hailed as the solution to all the problems of radio reception —which it wasn't—and inflated much as the "wonder drugs" of a later decade were to be inflated by an uncomprehending press. It was a mistake easy to make. Not only did superregeneration give tremendous amplification, but it was simple. Two tubes did all the work. In fact, even down to the present day, it is the only method ever discovered by which only two tubes can be made to receive weak signals of 800 kilocycles or higher at loudspeaker volume. Ironically, this invention was to be less widely used and to earn more money for Armstrong than any of his other far greater inventions, an irony deep in the mad pattern of the times and of the American economy.

With all the hullabaloo in the press, David Sarnoff was eager to buy the superregenerative circuit exclusively for R.C.A., to give R.C.A. a club to beat the increasingly rough competition. R.C.A. was still having a bad time. Small companies were introducing receiver improvements so fast that its cumbersome manufacturing partners, G.E. and Westing-

house, could not keep up with them. Gradually R.C.A. was whipping competitors into taking licenses under its patents, restricting them to the regenerative circuit, while R.C.A. planned to keep the superheterodyne for itself. Now, however, a group of independent manufacturers had gone to a professor at the Stevens Institute of Technology in Hoboken, New Jersey, named L. Alan Hazeltine, who had a circuit invention with which they might evade R.C.A.'s control.

Hazeltine, a friend of Armstrong's, had devised a most ingenious circuit called the neutrodyne that circumvented the big defect in regenerative reception—its propensity to slip into the oscillating state, emitting unearthly moans and howls. The independents persuaded Hazeltine to set up a patent-holding and research company in which they all took stock and licenses. Not only were they defying R.C.A.'s power, but the neutrodyne was soon shoving all other types of radio receivers to the back of dealers' shelves. Because of its economy and good performance, the neutrodyne was the most popular of all radio sets until the superheterodyne gradually came along to replace it. To R.C.A., Armstrong's sensational new superregenerative circuit seemed to be just the thing to break up this competitive situation. It would provide a low-cost, high-powered set with which to smash the opposition, while the "superhet" was being developed into the Rolls-Royce of receivers.

Armstrong, fresh from a sweeping victory over de Forest in the U.S. Court of Appeals, decided to negotiate the sale of his new circuit personally with Sarnoff. He was strongly assisted in these negotiations by a brilliant young lawyer on Pennie, Davis' staff named Willis H. Taylor, Jr., who also represented the Hazeltine group. Armstrong had learned a great deal since returning from France. He had seen A.T. & T. snap up the Frenchman Levy's far-fetched "superheterodyne" patent and begin to harass him with it in interference proceedings, until the whole matter became academic when

Westinghouse joined the big group and Armstrong's patent was cross-licensed to A.T. & T.'s use. Two could play at that game. Before going into negotiations with Sarnoff, therefore, he conducted a search of the patent literature to discover whether there was any patent remotely resembling super-regeneration in existence. There was one that might have passed, an English patent under the name of John Bolitho. Armstrong thereupon had his lawyers and agents quietly search out Bolitho. He was found some weeks later in the Egyptian Sudan and persuaded to sell his patent, which had seen little use, for a few thousand dollars.

Armstrong was ready for negotiations. These went forward a bit stiffly at first. The R.C.A. group seemed to be waiting for something. What they were waiting for, as it turned out, was a report from their agents who were belatedly on the track of Bolitho. When a cable finally came in to the effect that they would have to see a man in the States named Armstrong, who now owned the patent, R.C.A.'s reserves collapsed. In June, 1922, Sarnoff made a solid offer to Armstrong which he promptly accepted. Under its terms he received for the superregenerative circuit $200,000 in cash and 60,000 shares of R.C.A. stock, making him the largest individual stockholder in the company and eventually netting him far more money than both of his first two inventions combined. He also agreed to give R.C.A. first option on any future inventions, an option that was not to be presented for nearly fifteen years, and then with earth-shaking results.

The price paid by R.C.A. for superregeneration was an index of how badly R.C.A. wanted it. But Armstrong's strategy rankled deep in that corporate bosom, and the deal was not long consummated before it began to be apparent that R.C.A. would be a long time getting its money back. Superregeneration was not suitable to radio broadcasting as it was developing. Despite its spectacular amplification and other virtues, it had one bad drawback, apparent as more and more

stations crowded on the air: it was not able to separate stations cleanly from one another when they were close together in frequencies, and nothing could be done to make it more selective. Superregeneration was to be used later for such special purposes as police radio, ship-to-shore and emergency mobile services, where as a powerful, light receiver it could operate on well-spaced high-frequency channels. It also found use in a type of World War II radar known as IFF (Identification, Friend or Foe). And it remains one of the intriguing ideas in radio, which, if some way could be found to perfect it, would provide the lowest cost, highest powered radio set in the world. But, even in the early boom, superregeneration never got far in the big radio market.

Meanwhile, however, Armstrong and Harry Houck were putting the finishing touches on the superheterodyne, which was destined to solve the reception problem and to do for R.C.A. what the superregenerative had been expected to do. Houck had built a number of fine sets by then, with controls reduced to two knobs. Armstrong demonstrated one of these in Sarnoff's apartment early in 1923, for his relations with Sarnoff, then vice president of R.C.A., were still most friendly. Sarnoff was more than impressed. The engineers of his Radio Group had led him to think that the "superhet" was years away from practical manufacture, yet here it was, superior to anything on the market. He wanted to move fast.

Armstrong took another set up to the apartment of Owen D. Young, then chairman of R.C.A.'s board, and with a touch of the dramatic switched it on in the vestibule, all sets being still battery run, and walked in bearing a radio from which an opera broadcast was coursing with a clarity then unknown. Young was completely captivated. The next day Sarnoff canceled some millions of dollars in orders for older type sets already placed with G.E. and Westinghouse. He also scrapped some circuits on which his own first small research laboratory had been working. He was prepared to miss the

whole 1923 season in order to scoop the 1924 market with the superheterodyne.

R.C.A. was spurred to these drastic measures not only by poor business but by steadily mounting rumors that A.T. & T. was working on a superheterodyne of its own, preparing to enter the radio-set manufacturing business as well as broadcasting. It was, in fact, rumored to be about to install one of its new super-sets in President Harding's office in the White House. Sarnoff was prepared to go to any lengths to head this off. In mid-summer of 1923, however, his staff was still having trouble reducing the superheterodyne to a production-line basis. His laboratory chief, Dr. Alfred N. Goldsmith, came in to advise that the whole thing be abandoned and the previous order reinstated. When Goldsmith left, Sarnoff was, for one of the few times in his life, nonplussed.

"What'll I do now?" he asked.

"Why don't you call Armstrong?" said his secretary, a pert young lady named Marion MacInnis.

Armstrong was called, and in a few weeks of intensive work helped iron out the difficulties that usually beset anything new heading toward a production line. For this lift, plus Houck's "second harmonic" improvement patent, Armstrong received an additional 20,000 shares of stock from the grateful Mr. Sarnoff. After this latest deal was concluded, Howard met Harry Houck for luncheon in Morey's Bar and Grill in lower Manhattan, bubbling with humor. "We did pretty well today, Harry," he said, and silently wrote a check and slipped it across the table. It was for an amount about double anything Houck had expected to earn from his development work and improvement patent on the superheterodyne, a sum which with a later addition came close to $100,000. Meanwhile R.C.A.'s superheterodyne hit the stores in March, 1924, and sold so fast that orders piled up mountain high through the following Christmas. Altogether, this set made more money for R.C.A. than any set that was to

appear until 1927, when Westinghouse developed a superheterodyne that could be plugged into ordinary house current, eliminating batteries. For three years R.C.A. kept the superheterodyne exclusively to itself, meanwhile trying to overthrow Hazeltine's neutrodyne patents. By 1927, however, the radio business was too enormous for even a few giants to hold and R.C.A. was forced to license the superheterodyne to others.

At the pinnacle of the concatenation of deals and events in the winter of 1922-1923 Howard Armstrong was suddenly a millionaire. At then current prices his 80,000 shares of R.C.A. stock, which he held on to, were worth something over $3 million; by the 1929 stock-market peak, when R.C.A. hit $549 per share (on a new stock issue of one share for five), he was many times a millionaire. Altogether, by judicious sales and re-investments over a period of twenty years, he was to realize some $9 million from his holdings. This was a fairly modest sum compared with the fortunes to be made in the radio boom. But compared with the traditional rewards to inventors, it was phenomenal. It could have happened only in America in the mad Twenties, when gold was raining in the streets—albeit only in the more exclusive streets. Armstrong happened to have a series of capacious buckets handy—inventions without which the new radio industry could not have functioned—and the gold rained in.

Briefly then, on the heels of his legal victory and rumors of his sudden sparkling fortune, Armstrong became something of a celebrity. In that first wild wind of worldly success, short, precious and never to be experienced in quite the same way again, he was suddenly known. Reporters interviewed him, his associates and Professor Pupin. "I've just got one more thing to put over," reporters quoted him as saying, "and then I'm going over to Paree for a rest." Pupin pointed out for the edification of the press, with that sturdy forthrightness that never endeared him to the powers-that-be,

that it was invariably the independent worker in science who came up with the original ideas and not the research laboratories of the big corporations. "The latter do some very wonderful and important work," he continued, "especially in the refining and development of inventions, but the conditions of high efficiency under which they work hamper originality. You can't get a man like Armstrong to punch a time clock."

The press whizzed right on. Radio magazines erupted a rash of articles and pictures on the young "wizard," whose head had not been turned by fortune but remained solidly screwed on, bald, quizzical and reserved, standing quietly before his laboratory table like any young professor of science. An article in *Hearst's International* magazine summed up the verdict of the moment. "His name," declared the headline, "will soon be a synonym for the radiophone as that of Edison suggests the electric light or Bell the telephone." And in the raucous style of the era the article began: "Edwin H. Armstrong found the radiophone talking like a hair-lipped man and left it singing like a nightingale."

In that same issue, while finishing off a serial by H. G. Wells entitled *Men Like Gods,* the magazine announced the beginning of Sinclair Lewis' sensational new novel, *Babbitt.* The revolt of the younger generation was in full tide. Nothing perturbed, the George F. Babbitts were busily whooping up a saturnalia of false values and stock market speculations on a scale never before seen in this country.

Far above the sordid surface of the era, Howard Armstrong was walking on clouds. He was finally and irrevocably in love, crowning his fantastic good fortune with this most human touch of all. In his numerous trips up to David Sarnoff's office during 1922 his eye had been more and more taken with the lissom figure of Sarnoff's secretary. A tall, cool girl of twenty-two, Scotch and pretty, Marion MacInnis had come to work in the city in the closing year of the war from the small New England town of Merrimac, Massachusetts,

where the only industry was a carriage and wheel works, slowly dying from the impact of the automobile. Like many another girl of the era, with emancipation in the air, she had decided to strike out on her own. Independent, lively and witty, she crisply parried Howard's first advances.

"How'd you like to take a drive in a fast foreign car?" he suddenly popped out on a visit to the office in the fall of 1922. "I'm leaving for France on a vacation tomorrow and I intend to buy the biggest and most expensive car I can find to bring back." Marion MacInnis allowed that it would be nice to ride in a car like that, and there the matter rested temporarily.

Armstrong checked into the Hotel d'Artois, Rue la Boétie, Paris, early in October, 1922, on the flying vacation he had promised himself as soon as he had concluded his final deal with R.C.A. His first action was to purchase, for about $11,-000 in cash, a long low Hispano-Suiza, one of the royalty of European-made cars, with instructions to ship it to the States. When he went into the Paris branch of the Bankers Trust to arrange payment, he found there none other than his old Yonkers friend Tom Styles, working at a desk but vastly enjoying the leisure of Paris. Howard set out to persuade him that he was wasting his time in banking, that radio was roaring and that if he, Styles, returned to the States there would be a job waiting for him in the research organization he was planning.

Armstrong also renewed his acquaintance with General Ferrié and other wartime friends, attended an endless round of parties, motored out over the route of the old A.E.F. network, looked at the battlefields and did a little negotiating of European licenses on the side. At one of the parties, given by the *Société des amis de la T.S.F.*, a dinner *en l'honneur de M.* E. H. Armstrong, he was asked to present a paper on the superregenerative circuit. A diagram of the circuit was printed on the back of the menu, whose main dish was *Vol-*

aille cocotte Grand'mère, ending with champagne and *café*. The evening before the event, Armstrong came to Styles with a technical paper in French which he wanted translated in a hurry. Styles worked at it all night, only to discover on the following evening that it was Armstrong's paper on super-regeneration, which the Major had had cast into French and merely wanted translated back into English to make sure that his translator had been accurate. There was no relaxation with the Major even on vacation. On his way home late in November he stopped off in London to visit Henry Round, now a research engineer high in British Marconi's organization, to talk more radio.

The Hispano-Suiza was waiting for him on his return and it was a beauty, fawn-colored and sleek, with head-lamps like the eyes of a stag at eve. It was the wonder of the Warburton Avenue neighborhood. Howard was out almost every day polishing it and studying its mechanism with his usual thoroughgoing absorption. It was something more than a motor car. It was at once the symbol of youthful success and of obstacles overcome, of boyhood dreams and of the motorcycle he had sacrificed over his first invention, and finally of romance. He became so attached to it that he could never bear to part with it, even after it had long outrun its time.

Howard soon challenged George Burghard and his Delage to a race. The automobile "buffs" of that time patronized the Long Island Motor Parkway, a toll road built over the abandoned right-of-way of the old Vanderbilt railroad and the scene then of the Vanderbilt Cup Races. There, for a fee of one dollar, they were allowed to race over the 40-mile course, replete with curves, straightaways and narrow bottlenecks carefully placed at five-mile intervals. The goal was to do the 40 miles in 40 minutes. Time after time Howard attempted to beat Burghard's mark of 45 minutes, running out nearly every week to press doggedly away at it. Something

made him flinch at the narrows, however, involuntarily slackening speed, and he could never quite do it.

Some time in April he invited Marion MacInnis out for the promised spin. They went out to the Motor Parkway and the Hispano's speedometer rarely dropped below 75 miles per hour. This was the beginning of a whirlwind courtship which through the spring and summer of 1923, shifting up and down in prospects, was carried forward on rides to Long Island and up the Hudson, through dinner and theater parties.

One morning in May Howard telephoned George Burghard and mysteriously asked him to meet him that afternoon in the Columbia University Club on West 43rd Street, bringing his camera with him. Radio Station WJZ was moving that day into large new studios in Aeolian Hall on 42nd Street—R.C.A.'s latest challenge to WEAF and the A.T. & T. hegemony—and Howard proposed to climb to the top of the station's new antenna tower on the roof, some 400 feet above 42nd Street, there to have his picture taken, for what reason he would not say. Burghard, who never questioned anything Howard proposed to do, was on hand at the appointed time. They went quietly into Aeolian Hall and up to the roof, where Howard proceeded to climb the 50-foot tower and hang by his knees from a cross-arm projecting over the street far below. With his heart in his mouth, George snapped pictures. When they returned to the club, however, Howard began to have doubts of George's photographic abilities. He therefore called Willoughby's, a nearby photographic store, and hired a photographer to meet them in the lobby of Aeolian Hall a half-hour before the station dedication ceremonies that night.

He was going to perform all over again. He carefully dressed at the club in a dark suit, hat, gloves and silk muffler. And again they slipped up to the station's roof, with the photographer trailing. It was dusk by now and chilly,

with a stiff breeze whipping the mast. With his hat firmly down on his ears, Howard went through all his gyrations again, this time climbing to the very top of an open-steelwork sphere surmounting the tower and standing up there straddlelegged, his coat tails flapping in the wind. The photographer got his picture, while news of the feat leaked downstairs to the assembled dignitaries. Sarnoff was furious. He issued an edict that anyone who allowed Armstrong on the roof again would promptly be fired.

No one ever got a further explanation of this daredevil incident out of Armstrong. He always had been fascinated by high places, of course. But except for the fact that it was the Twenties and that young men in love in that electric time were apt to do almost anything and that he was probably stunting to show Marion that he was, indeed, a man of parts and not merely a dry brain upon a scientific stalk, no clearer explanation was ever forthcoming from even his closest intimates. Some time shortly after this event, Marion accepted his suit, and by fall the marriage was arranged for December 1 in the home of her parents, the Angus MacInnises, in Merrimac.

Marion went up to Merrimac by train some days before. Howard remained behind for a last bachelor dinner with his Radio Club cronies. A group of these planned to drive to Merrimac with him. Howard would drive the Hispano, needed for the honeymoon trip to Florida. Burghard, who was to be best man, would drive the Delage, with Johnny Grinan as companion on the ride. Early the following morning the caravan started off, gaily signaling between cars by Morse code on the horns. In the tonneau of the Hispano was a special superheterodyne carefully built into a large suitcase, Howard's wedding gift to Marion and the first "portable" radio in the world. All through the fall he had delighted in carrying it about in taxicabs to watch the suspicious glances of drivers, familiar now with the bootleg

trade, suddenly change to amazement as music burst forth from the heavy case. The caravan did not get far, however, before the Delage developed carburetor trouble. Howard stopped and cleaned all the spark-plugs and mechanism. George urged him to go on ahead so that he would not be late at Merrimac, but Howard wouldn't hear of it.

By the time they reached Bridgeport, Connecticut, the carburetor had been taken apart seven times and the trip was on the way to becoming an epic. No sooner did they strike the streets of Bridgeport than the Delage gave a final cough and died. Howard went into town to get a tow-rope and managed to tow the car as far as Hartford. By then it was dark and drizzling and the weary voyagers piled into the Hotel Heublein for the night. Next morning a mechanic informed them that the magneto was completely out. Armstrong knew someone at American Bosch in Springfield, ignition parts manufacturer, which might have the special magneto needed. He called, then ran over to Springfield and back to Hartford. They were finally off again, this time getting as far as Worcester, Massachusetts, where the battery fell out and the Delage was really stuck. By then so much time had been lost that Howard had to wing on to Merrimac, while George hunted a battery and barely made the ceremony by an eyelash. Nearly everyone was there, Charlie Underhill, Bill Russell, Tom Styles, who had returned to the States and to radio, and a host of relatives and associates. Marion's sister Marjorie was maid of honor. After the wedding, the climax was traditional. The married pair slipped out the back door to the purring Hispano, which promptly stalled, bringing on a rain of rice and missiles, one of which cracked the windshield. Thus they drove off to Florida.

The Florida trip was to top even the previous saga, for, as was apparent by now, Howard, who seemed so mild-mannered and reserved, attracted dramatics as a high-tension

wire attracts lightning. They made New York late on the first night, and on the second, Trenton. By the time they reached Washington, Marion had to go into a hospital to try to shake a severe cold contracted in the arctic breezes sifting through the cracked windshield and the curtains of the open tonneau. Howard, who would never easily give up on any project, pressed on alone. In Georgia, however, he got so thoroughly bogged in that state's red-clay gumbo that he had to crate the car and ship it on ahead by rail to Palm Beach, their destination. In West Palm Beach's Powhatan Hotel the two finally rejoined each other, and under the sun, the palms and the marbled roll of surf the honeymoon had a happy ending. A snapshot survives, taken on the beach, Marion in a smart dress and down-swooping hat, Howard in a stiff straw skimmer, tuning in the "superhet," a scene with some of the morning dew of the era still upon it.

They returned to New York by train, the Hispano-Suiza following by freight as the better part of valor, and took up residence at 86th Street and Riverside Drive, overlooking the familiar Hudson. The Yonkers days and attic workshop were now of the past, to be preserved, however, as he preserved every piece of apparatus he ever worked on. The heart of New York was henceforth his headquarters, battleground and home. Armstrong returned again to Pupin's laboratory and to Columbia University, where he was soon an assistant professor of electrical engineering, probably one of the strangest professors any great university has ever harbored. He refused to accept any salary now, not only from a sense of delicacy over taking money that he did not need and felt that he did not earn, but also out of a wily sense of self-preservation, to prevent himself from being trapped into endless administrative duties. He wanted to devote himself wholly to research. He taught no classes, and the few lectures he delivered were so elaborately set up and illustrated

that, on any regular basis, their cost would have been prohibitive. He was not to have much time to teach in any event. Almost as soon as he returned from the honeymoon, the de Forest matter, which he had thought was thoroughly cauterized, reopened like a festering sore.

Chapter 10

Armstrong vs. de Forest

"IT IS A CURIOUS psychological fact," remarked Michael Pupin in his autobiography, "that when one's claim to an invention is disputed one will fight for it just as a tigress would fight for her cub." Howard Armstrong returned to the fight in 1924 with a keenness that made that simile seem pale. It was to be the longest, most momentous battle of his life. With only a few false lulls and interruptions, it continued from 1920 to 1934 through more than a dozen courts and tribunals, piling up thousands of pages of testimony, wearing out nearly three sets of lawyers, costing well over a million dollars and rising in the end to a strange and terrible climax. Nearly a quarter of a century later it would still be a *cause célèbre* over which heated differences of opinion could be generated.

In this extraordinary trial of fourteen years' duration Armstrong's features were molded into that iron and tragic mask which he presented to the latterday world. One of the lawyers associated with him in later years made the illuminating observation that there were really three Armstrongs, closely related but distinct, contained in the same character but separated by the increasingly harsh attrition of events. The first of these was the easy, modest man of the private world who could relax swiftly among friends into intercourse of intangible charm and grace. This private man held a legion of friends over the years, with but one notable disaffection. The second Armstrong was the man of finance and affairs,

who could press forward aggressively to achieve his ends. A little apart from these figures stood Armstrong the inventor, proud and lonely and raised upon a pedestal, whom the other Armstrongs protected with the jealousy of a brother and whose life went forward in the intensely individual processes of creation, oblivious for long periods of even wife and friends. At the slightest threat to the image of the inventor, all the forces of the whole personality marshaled to repel the attack.

The battleline was inevitably drawn in the legal world. There is a generally held belief, not unfounded, that patent suits are among the most disreputable and tortuous forms of litigation. They often are. Yet almost no great invention of modern times has escaped this trial by litigation, heavy with polite billingsgate and incredible chicanery. The Wright brothers were forced to defend their clear and unexampled title to the principles of powered flight in dozens of wearing court tests between 1903 and 1912, sturdily winning all of them and emerging unsoiled as two of the most extraordinary characters the world has seen. It is the mark of a great invention as of a great man that both are fiercely attacked in their legal and natural lifetime, for the jealousy and cupidity of mediocrities around them are infinite.

Until society devises some more rational means to affirm the title and rights of its scientific creators, inventors have no other avenue but patent law by which to defend their creations. U.S. patent law gives the inventor, in return for his full disclosure of a new device or process to society, a handsomely embossed paper granting him exclusive possession, exploitation and assignment of his discovery for seventeen years. It gives him no more than this. It gives him no means to develop his invention or to carry it into use. It grants him no defense of his rights except that which he can muster for himself in a court of law by his own energies and resources. By the time an invention gets into court it in-

variably involves large industrial forces battling for position, and the drama becomes turgid. Yet it still pivots on the inventor. In the case of great inventions, the human drama rises to an unholy pitch, for it turns upon the determination of the actual moment of creation.

In all the Patent Office proceedings leading up to the court tests, Armstrong had no difficulty in establishing the effective and preemptive date of his regenerative invention as January 31, 1913—the date on which he as an undergraduate had had a sketch of his feedback circuit witnessed by a notary public. And he held clearly to his title of inventor as, in the years from 1914 on, the rivals Langmuir, Meissner and later de Forest pressed their claims upward through the intricate Patent Office tribunals and boards of appeal to the Commissioner of Patents himself. To these bodies skilled in the weighing of such technical issues, the order in which the men arrived at the invention, and the evidence for it, was clear: Armstrong, January 1913; Meissner, April 1913; Langmuir, August 1913; and de Forest, "sometime later." A single day or hour, if clearly established, is sufficient to award priority and the whole prize. Unclearest of all was the date on which de Forest claimed to have made the invention. Up to 1924, therefore, no patent on any aspect of the discovery was issued to him, though he had filed for a broad patent, it will be remembered, late in 1915. The only patent issued on regeneration was Armstrong's historic patent of October, 1914, by then ten years old.

Meanwhile, that historic patent had been doubly sustained in 1922 in the exhaustive court action before Federal Judge Julius M. Mayer and in a subsequent appeal before the U.S. Circuit Court of Appeals. Judge Mayer had had a long background in trying important patent cases in the electrical and wireless field through the early part of the century. Through weeks and months of hearings in the old Federal Court House in lower Manhattan the apparatus and the evidence

and the witnesses and the scientific facts were gone over and over. In equity suits of this kind the question of hard fact reigns. Armstrong as plaintiff, backed by Westinghouse, had to prove beyond doubt with corroborative documents, witnesses and apparatus that he was the inventor of the regenerative circuit and that de Forest was clearly infringing his invention. De Forest as defendant, backed by A. T. & T., had to try to overturn Armstrong's established priority to the invention and to prove himself the inventor.

Armstrong was immediately confronted by the fact that two of his principal witnesses were dead. Professor Frank Mason, the man to whom he had first disclosed his invention in 1913, showing him the notarized diagram and discussing its oscillating features, had been killed on a Navy destroyer in the war. Much more serious than this, the notary, a man named John A. Goodwin, who had signed the diagram on that blustery January day on Lenox Avenue so long ago, was also dead. And de Forest's lawyers produced the dead notary's commission to show that its signature did not conform with that on Armstrong's sketch. The lawyers charged Armstrong with forgery and fraud.

Armstrong and his attorney, Willis H. Taylor, Jr., the sharp young man on Davis' staff, spent feverish days tracking down Goodwin's widow, other notarized documents from his pen and a string of witnesses to prove the almost incredible fact that the dead notary actually had had two different signatures. The first of these was a flourishing affair reserved for what the notary regarded as important documents; the second was an everyday signature used for ordinary papers. Young Armstrong's paper evidently was in this latter class in the notary's view, for he had scrawled his plainest signature on it. Armstrong then proceeded to produce an overwhelming stream of witnesses—Underhill, Russell, Runyon, Styles, John Shaughnessy, Herman Burgi and other boyhood friends from Yonkers and Columbia who had witnessed the unprece-

dented amplification of his circuit in the winter of 1912-1913, Professors Morecroft, Arendt, Pupin and Schlicter of Columbia University who brought more substantive evidence to bear on the crucial turn of events in early 1913—to prove beyond doubt that he had made the invention no later than January 31, 1913.

De Forest's task was to show that he had made the invention prior to that. He based his case on a circuit diagram and entry, dated August 16, 1912, from a laboratory notebook kept by an assistant, Herbert Van Etten, which purported to be the first conceptual step in his discovery of regeneration and invention of the radio feedback circuit. Both de Forest and his assistant were then employed by the Federal Telegraph Company and working in Palo Alto, California. In addition, de Forest put forward another notebook entry, dated April 17, 1913, which consisted of a footnote appended to a recorded unsuccessful experiment, unsupported by any circuit diagram, stating: "This day I got the long looked for beat note—from a simple 2 pancake cabinet and series circuit (load coil on top of cabinet) but only by careful adjustment of Audion Battery A Rheostat. Then by adjusting loose coupling, variable condenser 1 and variable condenser 2, got the real 'heterodyne' phenomenon." With these cryptic words he asserted that he had unlocked the secret of continuous-wave regenerative reception. A final notebook entry was brought in indirectly from previous interference proceedings, in the hand of Charles V. Logwood, his other assistant, detailing experiments leading directly to the feedback circuit, dated early in October, 1913. No attempt was made to authenticate this notebook. It was used to fix a date shortly thereafter when de Forest claimed to have "reduced the invention to practice" by setting up a circuit in a New York amateur station owned by one John Myers—corroborated by Myers—and receiving signals from

an English station operated by one Cyril Elwell, a former assistant to de Forest in Palo Alto.

These three notebook entries constituted the only material evidence presented by de Forest at this or any subsequent trial to sustain his claims. The second notebook entry was dated nearly three months after Armstrong's established date. The third entry occurred some seven months after the crucial date, when Armstrong had been getting reception, before witnesses, from well-known commercial wireless stations all over the world. The whole case devolved therefore upon the nature of the first entry, five months before Armstrong's effective date.

Cross-examination and questions from the bench soon took apart de Forest's crucial circuit diagram of August, 1912. In the sketch of it presented to the Court two items had been omitted that were present on the original notebook page. One was the significant word "line" and the other was the interesting comment, "Found this arrangement no good for a two-way repeater." It was de Forest's famous "howling" telephone-repeater circuit which, while it achieved some amplification of low-frequency currents in a telephone line, was as unsuitable for telephone use as it was totally unconnected with radio.

Now, the "howling telephone," as Armstrong and his lawyers soon showed, was a phenomenon that had been known in telephony for well over thirty years. It was produced whenever, to the amusement of mischievous small boys around the turn of the century, the earphone of an old-fashioned telephone was held up to the mouthpiece on an incoming call, feeding back the incoming vibrations to the transmitter, causing the phone to sing and howl. It was an electrical phenomenon that had proved a troublesome obstacle to two-way telephone line amplification for many years, and de Forest's audion-tube circuit merely produced the same

kind of howls as electrical repeaters of years past. De Forest's circuit had nothing to do with radio reception or transmission and was totally incapable of performing either function. The howling tone was not an invention but only the simulacrum of a phenomenon that, properly understood and transformed in a different circuit, could lead to useful results. De Forest's experiments and action immediately following showed that he did not understand it, for he tried to get rid of the howl. He admitted on the stand that, at the time of these experiments, he did not perceive that the "howling tone" had any application in radio. Hence there was no conception, much less the invention of a radio device by de Forest on August 16, 1912.

To attempt to bridge the gap, however, between this early experiment, from which he asserted the idea of the invention flowed, and the later experiments in which the invention was given physical form, de Forest brought in as key witness a distinguished consulting engineer and early worker in wireless telephony, closely associated with American Telephone & Telegraph, named John Stone Stone. To Stone sometime in October, 1912, de Forest said, he had disclosed the "possibility" of using the phenomenon in radio. Stone did not directly confirm this on the witness stand, but said that de Forest had shown him a drawing of a circuit which he, Stone, had predicted some months before would produce the howling or "oscillating" effect. After reviewing the requirements that such a circuit would have to fulfill, in the light of 1921 knowledge, to be useful in radio, Judge Mayer put a question to the witness:

JUDGE MAYER: "As an engineer appreciating these requirements, did it occur to you that this disclosure by de Forest embodied an idea of extreme or unusual value to the radio art?"

MR. STONE: "No, I did not perceive any value."

With this admission, the value of the witness' testimony was thrown into doubt. Meanwhile, Armstrong, acting on a hunch and a long memory, had quietly caused an investigation to be made of the asserted regenerative reception of signals on or around October, 1913 between Myers' station in New York and the English station operated by Cyril Elwell. Armstrong had made Elwell's acquaintance in Europe during the war. Armstrong thereupon produced sworn affidavits from Elwell and others, secured in England, that the Elwell station had not been in operation before the late spring of 1914. Moreover, Myers returned to the stand, this time as Armstrong's witness, to assert that his memory had been faulty and that his station on Amsterdam Avenue in New York had not been in existence before the spring of 1914, either. Thus the supposed "reduction to practice" of October, 1913, could only have occurred at a much later date.

Equally weighty in the Court's adverse decision against de Forest was a commonsense consideration of his actions at the time he asserted he had made the invention. Though he was far more experienced in patent procedure than young Armstrong, de Forest in 1912-1913 did not act like a man who had made a great discovery and was anxious to protect it. He made no move to patent anything resembling a radio feedback circuit in this period, during which he was filing for over a dozen patents on lesser things. A month after his August, 1912, experiment, having managed to smooth out his telephone-repeater circuit, he was off to visit New York, where Stone had arranged a demonstration before A.T. & T. engineers. He was still working for Federal Telegraph in California, where he had the specific task and full laboratory facilities to try to develop a better wireless receiver. Yet neither to Federal Telegraph nor to A.T. & T., to whom he was trying to sell his repeater circuit, did he offer throughout this period the far more commanding prize of a radio-frequency amplifier, for which both the wireless and tele-

phone worlds were searching. A year later in the fall of 1913, de Forest, having quit Federal Telegraph to return to the struggle with his moribund Radio Telephone Company in New York, made his first famous sale of wire rights on the audion to A.T. & T. for $50,000. Still no hint or sign that he had anything more valuable to sell.

When in March, 1914, de Forest finally applied for a patent on something approaching a regenerative circuit—by which time news of Armstrong's discovery had been coursing through the wireless grapevine for months—it was for the incredible "ultra-audion" which de Forest maintained involved no regeneration whatsoever. The laboratory notebook pages recording this device bore the excited notation: "Patent this." And within three weeks a patent was being applied for. Yet within the year the "ultra-audion" was shown to be an incomplete type of feedback circuit. De Forest sold some of the new circuits to the Navy, which soon found them defective and ordered him to insert tuning coils in the plate circuits to make them regenerative circuits of the Armstrong type. If de Forest had had the secret of regeneration well before March, 1914, why bother to patent something embodying less than half of it?

Yet the really undownable fact was that de Forest had made no move to seek a patent even mentioning regeneration or a radio feedback circuit until September, 1915. This was three years after the alleged August, 1912, date of its invention, two years after he said he had reduced it to practice, one year after the issuance of Armstrong's historic patent and six months after Armstrong had delivered his two scientific papers explaining for the first time how the three-element electron tube and the regenerative circuit operated. That a man of de Forest's patent experience had possessed this great secret from August, 1912, to September, 1915, without attempting to make it known to the world and without at-

tempting to protect his rights in it passed far beyond the bounds of credibility and ordinary human behavior.

In awarding the decision to Armstrong, and laying the basis for assessing damages against the de Forest company, Judge Mayer held forth at length on Armstrong's proofs and achievement. "It is necessary to recognize," said the jurist, "that Armstrong is a remarkably clear thinker. His modest demeanor belies his extraordinary ability. His achievement was not the result of an accident, but the consummation of a thoughtful and imaginative mind." This decision was upheld in March, 1922, by the Second Circuit Court of Appeals in a biting opinion written by Judge Martin T. Manton. It seemed a final and complete vindication.

In the months following, however, Armstrong moved in a characteristic way, with far-reaching consequences that he hardly could have foreseen. By a concurrence of events, including the death of a Special Master appointed to assess damages, delay in naming another and the imminent bankruptcy of the de Forest company, no damages were drawn against de Forest. Until damages are drawn up and approved by the court or waived by the winner, no final judgment can be entered in a patent case. But Armstrong would not allow Westinghouse to enter judgment by waiving damages against de Forest—in which case the issue might never have been reopened or gone on to its irrevocable conclusion—for Armstrong wanted damages assessed. There was great vanity in his inventive alter ego and great stubbornness in defense of his rights, which appeared in his view in uncompromising black and white. When de Forest, still pressing his interference suit in the Patent Office in Washington, made moves toward a truce by acquiring a small company holding a license under the Armstrong patent and then made attempts to pay royalties to Westinghouse, Armstrong would have none of it. Against the advice of Westinghouse lawyers, he pressed to have de Forest's purchased license canceled.

When it became clear that Armstrong was going to exact penalties from de Forest and possibly from those behind de Forest, even though no benefits could accrue to himself, the defense stiffened and the feud between the two men ran on deeper and more bitter than before.

The character of Lee de Forest as exhibited in these and other proceedings is one of the most mixed and curious in all American science and invention. His life—drawing to a close at the age of eighty-two as this is written—lies spread out in scores of court records, documents, his autobiography and annotated histories of radio. From the moment he emerged, penurious and ambitious, from Yale's Sheffield Scientific School with a doctorate in 1899, he plunged into a furious struggle to rise. The struggle continued with great and often misdirected energy for many years. Altogether he organized over twenty-five different companies at different times, many of them associated with malodorous stock-selling schemes, most of them badly managed, all of them finally bankrupt. He had no talent for business or associates, some of whom went to jail for fraud. All told he made and lost three fortunes in a frantic series of ups and downs. He also was married three times and divorced twice.

His inventive life had a similarly wild and gamy flavor. Entering wireless shortly after Marconi had established his basic wireless system, de Forest set out to find patentable devices that would get around Marconi's patents. Marconi sued and finally won an injunction that helped put one of de Forest's early companies out of business. Indefatigably, de Forest moved on, trying to find a receiver or system that would circumvent Marconi. The search was twice interrupted by injunctions secured by Fessenden against de Forest companies for appropriating receiving devices belonging to Fessenden. Late in 1904 de Forest returned from a trip to England, where the wireless world was abuzz with news of the Fleming valve, which its inventor was to expound in a

historic lecture before the Royal Society in February, 1905. De Forest promptly resurrected and patented an old experiment of his own in which he had attempted to use a Bunsen-burner flame between two electrodes as a wireless detector, with no practical results. Then in swift order between 1905 and 1907 he filed ten additional patents in which the Bunsen-heated electrodes were enclosed in a tube, the enclosed electrodes were alternatively heated by electricity, the number of electrodes was increased and the electrodes shifted about, until there finally emerged the three-element vacuum tube with wire grid as known to history. When Fleming finally sued for infringement of his valve, de Forest was thoroughly prepared for a counter-suit in which he claimed that he had independently reasoned out the whole invention from his Bunsen-flame device. The courts rejected his curious reasoning and held that he clearly infringed Fleming; but the courts also held that Fleming in any use of a grid element infringed de Forest. Both were enjoined from using each other's device. The situation was now so tangled as to be unworkable.

De Forest refined his methods with time. In 1914, after the appearance of his "ultra-audion," A.T. & T. approached him to buy additional radio rights on the audion, which he sold for $90,000. Shortly thereafter he began to notice a string of circuit patents being issued to A.T. & T.—"so similar to some I had been using," says his autobiography disingenuously, "that I began to file applications of my own deliberately making identical claims." And he added: "This I did for the purpose of interference." De Forest was continually selling some rights under his patents, reserving others to himself and getting into legal tangles over subsequent developments. To cut short the growing entanglement, A.T. & T. made its final purchase of all commercial rights on the audion, plus any future developments for seven years, for $250,000 in 1917. Thereafter de Forest's inventive

interest shifted to "talking pictures," on which he had begun to secure patents as early as 1913, and he made no more contributions to radio.

There is no doubt that de Forest pushed the early development of wireless and radio with great vigor and showmanship. Tireless and jaunty, never long cast down by setbacks, he pushed on with or without clear patents of his own. And incontestably, by whatever fantastic process he chose to believe that he arrived at it, he put the third and controlling element in the vacuum tube—the one really important invention among the more than 300 patents issued to him. This one invention, in the words of Nobel Prize physicist Isidor I. Rabi of Columbia University, was "so outstanding in its consequences that it almost ranks with the greatest inventions of all time"—for it provided the instrument from which all electronics developed. But de Forest was not content with these laurels; he must also have all credit for the ensuing "consequences."

From 1906 to 1913, as we have seen, his great invention lay fallow. Seven leading textbooks on wireless telegraphy published up to 1914 contained less than a page among them on the audion tube, and then only as another detector of wireless signals. Though he was a doctor of science, de Forest could not satisfactorily explain his invention. One of the reasons he could not do so was that he was so intent on proving that he had derived it from the Bunsen-flame experiment, independently of Fleming, that for years thereafter he stoutly held to the entirely erroneous theory, preserved in all his technical papers and utterances up to as late as 1915, that the tube's basic action was the passage of a current by a heated gaseous medium. Self-interest led him completely astray and blinded him to the most important observation to be made on the currents in his tube.

As Armstrong's feat began to be rumored in demonstrations from the spring of 1913 on, de Forest was thrown into

a pitch of feverish activity. This is shown by his laboratory notebooks, made a part of the court record, in which he is seen trying one circuit arrangement after another in random attempts to get at the secret. Sometime late in 1913 he or his assistant Logwood began to get a glimmer of what Armstrong already had accomplished, but a glimmer is not an invention and there was still much to be done. Since 1907 he had been so close to it and yet so far that it seemed inconceivable that somewhere in his many experiments there was not some seed that he had overlooked. As the Armstrong circuit was disclosed to the world in 1914—so simple, why had no one thought of it before!—de Forest was ready and eager for the well-known patent game of "carrying back the date." It is a common feature of this game that the deeper the contestant gets into it, the more convinced he becomes that he had the invention all along. By 1924, even after major setbacks in the courts, de Forest thoroughly believed that he was the inventor of the regenerative circuit.

In 1924 de Forest managed to get his first legal victory to bolster this belief in nearly ten years of trying. In this turn of events the troubles Armstrong had sown for himself in 1913 by filing for two separate patents on regeneration began to come to harvest. As will be remembered, Armstrong had filed first for the receiver functions of his feedback circuit, on which the historic patent of October, 1914, was issued; a few weeks later he filed for the oscillating or transmitter functions, and this application had been embroiled ever since in interference proceedings. None of the other claimants adopted this split approach. Had Armstrong like the others filed a single application on both the receiver and transmitter functions, the issuance of his first patent might have decided the issue. At least there would have been fewer loopholes for interminable interference proceedings in the Patent Office. Out of this labyrinth in 1924 de Forest plucked a decision from the District of Columbia Court of

Appeals ordering the Patent Office to issue to him forthwith patents on both the "ultra-audion" and his regenerative application of September, 1915.

A proper description of interference proceedings in the U.S. Patent Office requires the genius of a Dickens or a Balzac. When two or more inventors file applications claiming the same invention, they are in interference. A Patent Office examiner, an expert in his particular field, thereupon draws up a succinct description of just what exactly the invention is. This description is in the form of essential claims, which then become the "counts" or issues against which each of the applications is measured, along with the priority of the inventors' claims. Under rules of procedure laid down and built up over the years by the District of Columbia Court of Appeals, then the ruling body over the Patent Office, counts must be interpreted "as broadly as their language will permit." As the interference wends its way up through the Patent Office tribunals, it thereupon becomes a word game, each contestant trying to stretch the language of the counts and to get it changed here and there to cover his outermost claims. Soon all rational contact with the facts at issue is left far behind. In its extreme forms the word game finally reaches semantic heights where nothing is at issue except the comparison of scraps of paper and the words written on them.

For many years this procedure has been one of the sorest issues in all objective studies of patent law, for it has led to some of the most monumental legal absurdities ever perpetrated. The classic example is a case in which two inventors claim the invention of a fine-tooth comb, and the patent is eventually awarded to the second man, who was demonstrably later in development, because at some earlier date he had once built a picket fence which could be described in some of the same terms as a fine-tooth comb. The example is not very far from the actuality. In 1915 the District of Columbia

Court of Appeals decided that the first man to conceive and build a hose extension on a vacuum cleaner was not the inventor but was anticipated by a rival who had once sold vacuum cleaners with a hole in the suction chamber for maintenance purposes, a hole into which he might have inserted a hose extension had he thought of it. And in 1921 the same Court ruled that the man who invented the hydroplane was not Glenn Curtiss, who was the first to build and fly one, but another man who had once applied for a patent on a boat with wings, which was never built or flown. Both decisions were eventually overthrown by higher courts, but only after long battle.

Thus it mattered not that Armstrong was demonstrably the first man to build, operate and explain the radio regenerative circuit; that in his first clear and issued patent he referred seven times to the fact that beyond a certain stage of amplification, as night follows day, the circuit became a generator of high-frequency oscillations; that, recognizing his mistake in filing for separate patents, he later came to abandon his second application, holding that the oscillating or transmitter functions were implicit in the circuit. The interference was joined because he did not clearly claim in his first patent the transmitter uses—and so the word game began.

In this kind of infighting de Forest and his lawyers were past masters. Right after the war, when Armstrong was still in France, de Forest moved to have one word changed in the original description of the invention as drawn up by the examiner in 1917. Two of the three essential counts began with the words: "Means for producing sustained high-frequency oscillations, comprising . . ." De Forest wanted the word "high-frequency" changed to the more inclusive word "electrical." The motion, being denied, was rushed before a Patent Office law examiner, an expert versed only in the art of procedural forms, and he sustained the motion

with a learned, unscientific essay on the objectionable fuzziness of such words as "high-" and "low-frequency"—though within those terms was all the difference between radio and telephone devices. Armstrong's attorneys, delayed by their client's absence abroad and the clogged condition of communication lines, were two days late in getting an appeal to the Patent Office. Later Armstrong tried to get a rehearing, but it was denied. Hence the reframed counts now stood as broad as a circus tent, ready to cover not only de Forest's telephone repeater circuit of August, 1912, but also prior "howling" telephone circuits of revered memory, not even patentable.

The Patent Office tribunals were not diverted by this change in words, for each claimant was still claiming broadly "Improvement in Radio Signalling Systems." From 1919 on they still continued to find that Armstrong was the inventor. Exhausting these tribunals, de Forest took his case to the District of Columbia Court of Appeals. There, under one of that Court's broadest interpretations of the "language of the counts," the decision went to de Forest on the basis of his 1912 telephone repeater circuit, which in effect was declared to be the invention, though it had nothing to do with and was unusable in radio. "We are not here concerned," said the Court in its best *Alice in Wonderland* manner, "with the question of whether the production of electrical oscillations be of radio or audio frequencies, or to what particular use they are put." Which was to say that the Court was not concerned with whether the invention was a fine-tooth comb or a picket fence, or whether a picket fence could be used to comb the hair. Under the iron rules of interference, the winner takes all. Thus it was that in 1924 the Patent Office was finally forced to issue to de Forest patents covering all of regeneration.

The fantasy now reached unbelievable heights. Two men held patents to the same invention. The District of Colum-

bia Court did not overturn Armstrong's prior decisions in New York where, in an equity court sifting all the facts, he was still held to be the inventor. In fact, the District of Columbia Court, in its stoic refusal to understand the invention, specifically ruled that the prior decisions were not in point, as they involved an entirely different issue. To add to the fantasy, the whole issue was in a sense academic, for both inventors long since had sold their patents, which were now cross-licensed for use between Westinghouse and A.T. & T., who were the real owners as well as the real contestants in this litigation.

Yet the fearful charade went on. A new suit was entered in the District Court for Delaware in which the three unsuccessful claimants, Armstrong, Langmuir and Meissner, sued de Forest and one another, each praying to be declared the rightful inventor. De Forest, now strongly supported by A.T. & T., struck back with a suit in Philadelphia against Westinghouse to have Armstrong's historic patent declared null and void. Having thoroughly confused the issue between an amplifier of telephone currents and one of radio frequencies and riveted that confusion into a court decision, de Forest rode hard on the presumptive validity of his new patents and the assumption that the District of Columbia Court had decided the issue. The blows came fast. He won in Delaware. He knocked out Armstrong's regenerative patent in Philadelphia, a patent which then was twelve years old and had been upheld in numerous infringement suits since 1920. And de Forest also won when both suits were carried to the Third Circuit Court of Appeals.

In all these and subsequent decisions no criticism can attach to the judges or the courts. They were deciding the issue to the best of their ability and their lights. Judges unschooled in science were being called upon to settle complex scientific matters in which they had few points of personal reference or knowledge. In their decisions they had to rely

heavily on the briefs of counsel and on records grown mountainous and confusing. Radio circuits were not as easy to understand as vacuum cleaners, hydroplanes or earlier inventions. The illimitable verbal confusion that legal counsel could bring to a discussion of electrical currents and electronic circuitry made just decisions difficult. Almost from the moment of Marconi's basic invention, wireless had provided a field for legal obscurantism quite unlike anything seen in other industries. By 1927 it appeared that the field was all de Forest's.

Armstrong had entered this battle in 1924 confident that the facts must eventually prevail. The battle did not then completely dominate his life. Indeed, in 1925 he began to get on the track of a new invention that, weaving in and out of all these fateful years, was to be the capstone achievement of his life. In the fall of 1925, too, he and Marion Armstrong piled into the Hispano-Suiza, picked up his mother in Yonkers and made a sentimental jaunt to Derthick Farm in upstate New York, the scene of some of his fondest boyhood recollections. And there were other relaxations. George Burghard was married by then, too, and the couples saw a good deal of each other. George played tennis and quietly saw that Howard got enough exercise, drawing him into tournaments at the Amacasson Club in Yonkers and, winters, at the indoor Island Tennis Club. Summers were spent on Long Island's Southern Shore near Bayport, where the Armstrongs rented a house and where for a season or two the Burghards rented near by. The Long Island shores were at the height of the social swirl of the Twenties, but Howard never strayed far outside his radio interests. In the summer of 1927 he had a diverting bit of play negotiating the acquisition of the steel ball atop Aeolian Hall which he had climbed only five years before. The tower was already being torn down to make way for a larger WJZ transmitter at a new site, and Armstrong was an indefatigable saver of

memorabilia. He was in receipt of a whimsically solemn communication from R.C.A.'s engineering department, which read:

"In accordance with your request, we are arranging with the contractor who is dismantling the Aeolian Hall towers, to set aside for you, one of the balls from the top of one of the towers. It will be appreciated if you will kindly arrange to have this taken from the building as soon as possible as the steel will be taken off the roof very shortly."

Never far in the background, however, was the legal battle he had no intention of quitting. As the decade wore on it filled more and more of his thoughts and conversation. This was a battle into which Marion Armstrong could enter intimately, for she had had enough immersion in the industry to be able to follow its twists and turns. Burghard, with his legal background, was a ready counselor. And all Armstrong's amateur and professional friends, who had lived through the facts of the case, rallied to the cause, which became a leading and sulfurous topic at meetings of the Radio Club and the Institute of Radio Engineers.

It was unthinkable that this first and most basic of his inventions, sustained in every court in which the full burden of facts was weighed, should be taken from him at this late date. It was no longer a question of money, for he had sold his patents. And anyhow, money, as his whole life was to show, was simply a means to independence and more research and a carrying on of the battles these entailed. His honor as a man and an inventor was at stake. And not merely his own honor, but that attaching to the proud title of inventor and creative man everywhere, which would soon become meaningless if it could be bandied about by those able to command the biggest legal battalions. He would take it to the Supreme Court.

On Thanksgiving Day, 1927, a young lawyer was toiling

in the offices of Cravath, Henderson and de Gersdorff in lower Manhattan when a senior member of the firm, Frederick H. Wood, called to ask him to stand by for a conference. An inventor was coming in who wanted to carry an action to the Supreme Court. The firm was largely a corporation law firm, but it had had wide experience before the Supreme Court and had dealt with many important patent cases. The inventor had soured on patent lawyers and wanted a leading trial lawyer to handle his case, and Wood was one of the best. The young lawyer called in, named Alfred McCormack, happened to be the only one about the office that day with, coincidentally, some qualifications for sitting in on the conference. Only two years out of Columbia Law School, he was fresh from a one-year term as law clerk to Supreme Court Justice Harlan F. Stone. Armstrong took to the young lawyer immediately, for he was able to answer straight out Armstrong's questions concerning a petition to the high court. When it came time later to write the brief, Armstrong insisted that Wood have young McCormack drop all his other work to help in its writing, and thereupon began another of those long associations that marked Armstrong's life.

Before he would allow McCormack to put pen to brief, the Major set out to give him a basic course in electrical science. Each morning he would appear sharply at nine-thirty in McCormack's office to begin the instruction, which usually ended anywhere between dinner and midnight. From time to time McCormack would reduce his new learning to a typescript, which the Major would read and criticize. This went on for three months. Strenuous as it was, McCormack, who had graduated at the top of his law class, was fascinated by the man and the graceful movement of his mind through the laws of nature. When the grounding was ended, there were the voluminous records of the case to be gone through as they hammered at the beginnings of a brief.

Through all the long summer of 1928 the hammering went on, in readiness for the October term of the Supreme Court. Armstrong spent only two weekends out on Long Island that summer, and on both occasions he took McCormack and the records along. Even when they went down on the beach, the records had to accompany them.

As late as the day before their Supreme Court appearance, they were still correcting galley and page proofs on the brief at a New York printer. When it came midnight and the task was still unfinished, it was apparent that they had missed the last regular train to Washington that would get them there next morning in time for the opening of the Court. Picking up a telephone, Armstrong called the head clerk of the Pennsylvania Railroad ticket office and informed that startled official that he wanted to hire a train to Washington. When the clerk was finally convinced of his sanity, he wanted bank references. A vice president of the Chase National Bank was routed from bed to attest angrily that he, Armstrong, had money enough to buy any of their damn trains. Shortly after four A.M., with only minutes to spare to catch the special train made up for them, Armstrong, McCormack and a Westinghouse lawyer trotted into Pennsylvania Station. A conductor, porter and train crew bowed them into the center car of a three-car empty train. Berths were made up and everyone went to bed. Hardly were they asleep, it seemed, when the sun was streaming in the windows and the train ground to a halt. McCormack, keyed up from weeks of tension, leaped up and was nearly dressed when he discovered that they were only in Trenton. Some three hours later they wanly pulled into Washington. The fare, as shown on a ticket dated October 18, 1928, was $1,200.

They then discovered that the Court hearing had been postponed for a day, giving them time for sleep. Next morning they assembled in the august room presided over by the nine robed men. Here oral arguments were heard from the

contesting parties and briefs handed up. The leading counsel for A.T. & T., especially retained for the occasion, was tall, bearded Charles Evans Hughes, onetime Republican candidate for President, who rested the defense's case on the argument that the verdict of previous courts should not be overturned. In his brief he made one point that particularly roused Armstrong's ire. Relying on records prepared for him, Hughes argued that "counsel for Armstrong entered no opposition whatever" to de Forest's 1919 motion to broaden the language of the interference counts from "high frequency" to "electrical" oscillations. Armstrong never got over the shock that a lawyer of Hughes' standing would hand up a brief containing, in Armstrong's super-sensitive view, such a misstatement of fact. In the weeks following he engaged in a correspondence with Hughes, trying to get him to change the point, but to no avail.

Marion Armstrong had motored down for the hearing, planning to go on to Florida for a vacation with Howard's sister Cricket, for the months of preparation had been almost as exhausting for her as for the participants. Driving away from the Court, she saw old Thomas Ewing, former Commissioner of Patents and an old Armstrong friend from Yonkers, standing on the street shaking his head, having just come from the Court himself. She gave him a lift to his hotel.

"I suppose you think my head was shaking because I am an old man," he said, "but I have just seen the gravest injustice in all my experience." He was referring to the Hughes argument for the defense.

Ten days after the Supreme Court hearing a memorandum opinion was handed down that read in full:

> "*Per curiam:* Affirmed on the authority of Morgan v. Daniels, 153 U.S. 120; Victor Talking Machine Co. v. Brunswick Balke-Collender Co., 273 U.S. 670."

This meant not only that Armstrong's plea was denied but that it was denied on legal precedent, as argued by Hughes, without passing on the facts. In the ten days between argument and decision, the Court was in session and could hardly have had time to master the facts, much less examine the voluminous record. A petition for a rehearing also was later denied.

The case was now forever closed to the parties at dispute, except for one remaining avenue. The issue could be reopened for at least one more try at a decision by any member of the public who found himself injured through enforcement of the de Forest patents. As long as there was one possible avenue, Armstrong did not give up hope that the case could be retried. He bided his time. De Forest had met an adversary outdoing anyone he had ever before encountered. But Armstrong was now alone in the battle. He had been backed in his Supreme Court case by both Westinghouse and R.C.A., which were then allied in fighting A.T. & T., but neither was now disposed to butt its head against a stone wall. Only an individual of great and stubborn power could elect to do anything so foolish or heroic.

Meanwhile, the bloom had long been off the decade. It was now in the last overblown stages before the Crash, when to suggest, in the frenzied stockmarket speculation and mass delusion that gripped nearly all America, that there was anything unsound in corporate values was to be counted un-American. The ill-fated Great Engineer, Herbert Hoover, had ascended to the Presidency in 1928, and from the White House and the offices of great business enterprises alike puffed large confident statements as to the eternal soundness of things. Almost no attention was paid to the depression that long before had begun to creep in on the farms and among the people. But there was an underlying jitteriness. Many of Armstrong's friends who had been playing radio stocks through the decade now sold out and urged him to do

likewise. Armstrong, however, solidly held on, chose a good peak of $114 a share at which to sell a block of his R.C.A. stock just before the Crash, and emerged with a big profit unscathed. In the mood of those last euphoric months of the Boom, he wrote a typical letter to Marion in Palm Beach in February, 1929:

"It is a coincidence . . . but I am feeling rich at the moment as we had a field day in Radio and Victor. Tell Crick she made a barrel of money arbitraying [sic] Radio and Victor . . . Now sweetheart—don't feel too badly on account of the decision—it would have been a great thing to have won the case here, but it will be a far greater thing to win it after a defeat by the Supreme Court. And the issue which is now raised is tremendous and to prove the truth after all these defeats . . . would be the greatest thing that has been done in the history of litigation. That is what we are going to do. Love. Howard. P.P.S. Save this letter as a souvenir when we win this thing."

Through all the corrosive vapors of the decade he still retained much of his innocence. The pursuit of science and radio was his shield and armor. In the summer of 1929 Captain Henry Round came to visit him from England. The two promptly became engrossed out on Long Island in tracking down the first wireless shack built by Marconi in America, which Round remembered as having been erected about 1900 near Babylon. They found it, in a vacant lot, being used as a paint shed, and Armstrong at once bought it and presented it to R.C.A. President David Sarnoff. The structure was removed to the company's big station at Rocky Point as a memento of the first wireless in America.

When the Crash came, Armstrong rode through it, not unaware of the enormous wreckage. He was in his broker's office on Black Tuesday, October 29, when amid the pandemonium he noticed a foreign-looking woman on the verge

of collapse. He took his broker aside and told him to cover the woman's account to any reasonable amount, anonymously. Two years later the broker received a letter addressed "To My Unknown Benefactor" from a grateful lady of Warsaw, Poland, named Nadine Sobansky, who was never to learn who had saved her funds. Just before the Crash, the Armstrongs moved to a large new apartment building overlooking Central Park at 81st Street, which remained half vacant all the while they were there. Families doubled up and crept in and out as if the world had ended, but this was only a small part of the destruction visited upon the country as a whole.

In 1931, never to be deterred from his purpose, Armstrong found the chance to reopen the de Forest battle for which he had been waiting. A small Brooklyn company known as Radio Engineering Laboratories, Inc. was being sued for infringement of the de Forest patents by R.C.A., which had administrative rights to the patents all along under the old 1919 Agreement with A.T. & T. Armstrong stepped in behind the small company and prepared to fight its battle and his own all the way up to the Supreme Court again, if necessary, this time entirely with his own funds. To insure the small company's stability, his old Yonkers friend, Randy Runyon, who was by then an executive of a large coal company, though still a fervent radio "ham," stepped in and secured an option to buy the company any time within the next ten years.

The first legal round was lost in the U.S. Eastern District Court of New York, which held that previous decisions had decided the issue. But in the Circuit Court of Appeals Armstrong got not only a reversal of this decision but what was in effect an electrifying reversal of the Supreme Court itself, whose 1928 decision was held not to be binding upon the defendant. In reexamining all the facts—which now included the additional facts that de Forest's key witness John Stone

Stone had been on A.T. & T.'s payroll from the time of his 1921 deposition on, and that a replica of de Forest's 1913 "2 pancake circuit" was incapable of regenerative action as he had described it—the Circuit Court of Appeals found for Armstrong in 1933.

In writing the majority opinion, Judge Harrie Brigham Chase threw a beam of light where since 1924 there had been darkness. "While we have the greatest respect for the conclusion which has been reached in the Third Circuit [the 1927 Appellate decision favoring de Forest]," said the Court, "we are confirmed by this record in the belief that Armstrong's discovery of the hitherto unknown existence of radio frequencies in the plate circuit and the regenerative feedback of these frequencies to the grid circuit gave the necessary novelty to the invention; that the work of de Forest in 1912 did not disclose these essential facts to him or to anyone else; and that the contrary results which have been reached on the facts have been due to a divergence of opinion as to what really was the invention."

But the light was soon to be snuffed out. Now de Forest, backed by both A.T. & T. and R.C.A., moved in his turn to the Supreme Court to petition that his patents and the Court's previous decision be sustained. And again the high court took up the case, this time devoting a month to its examination of the facts and the record. On May 21, 1934, in a lengthy opinion written by Justice Benjamin N. Cardozo, the Court upheld its previous decision and sustained de Forest. Again on the citation of *Morgan v. Daniels,* the Court held that the District of Columbia and the Third Circuit Courts of Appeals had presumptively established the priority of de Forest and that any infringer—meaning Armstrong—must bear the heavy burden of persuasion that the facts were otherwise.

The nub of Cardozo's opinion was that the Supreme Court accepted de Forest's contention, supported only by his own

testimony, that he had reasoned out the invention from his August, 1912, telephone repeater circuit. While de Forest had many witnesses to his 1912 telephone repeater, he had no witness to the mental processes by which he later claimed to have seen, prior to January 31, 1913, the germ of a radio amplifier-oscillator in the howling tones emitted by this telephone device.

Just here, on the crucial point, the Court boggled or was deluded on the scientific facts. For as late as 1915 de Forest was maintaining before scientific bodies that a positive or negative charge on the audion's grid alike produced only a diminution in the plate current, which meant that he was unaware that the audion tube could pass any alternating or radio-frequency currents. Moreover, his telephone repeater lacked two vital elements to make it anything approaching a radio device: a means of controlling the frequency and a means of controlling the strength of the alternating currents which de Forest at the time was stoutly maintaining were not even there. He explained this away later by saying that he had varied the frequency or pitch of the "howling telephone" by altering the strength of the battery current. But this proved only the opposite of his contention. It proved that his device was not even remotely a radio oscillator or amplifier, the essential characteristics of which are that the frequency is completely independent of current strength and is controlled solely by inductance and capacity. These were facts not subject to judicial opinion but provable by scientific law and experiment. Hence, whatever he might have done, de Forest did not reason out the regenerative radio circuit invention from his telephone repeater of 1912. On the basis on which the Supreme Court decided the case, the invention might more justly have gone to Vreeland's mercury-vapor-tube circuit of 1905, for this circuit, though it was no more a radio device than de Forest's telephone re-

peater, was a feedback circuit and regenerator of *electrical* currents antedating de Forest by seven years.

As the mandate of the Court was stayed for three weeks to hear a petition for rehearing, Michael Pupin, Alan Hazeltine and other scientist friends of Armstrong raised a hubbub in the press over the Court's garbling of scientific fact. And in demonstrations in the petition for rehearing it was shown that it was a palpable error to consider the telephone repeater as a controllable radio device or the invention at issue. But the petition was denied and Cardozo retreated only to the extent of making one slight but significant change in the wording of his opinion as it was finally printed.

In reviewing the basis on which the Court decided for de Forest, with particular reference to the one laboratory notebook page and circuit diagram by de Forest's assistant Van Etten on which the whole case now rested, Cardozo's original opinion, handed down in May, 1934, had stated: "On August 6, 1912, a diagram showing a feed-back hookup of the input and output circuits is recorded in Van Etten's notebook with a note that by the use of the coupling 'a beautiful clear tone' had been developed, which means that oscillations had been produced and that the oscillations were sustained. There is also a note that the pitch, i.e., the frequency, was varied by altering the plate voltage, which means that the frequency could be varied at will." In denying petition for rehearing in October, 1934, the Court ordered the last phrase of this quotation struck out and amended to ". . . which means, or was understood, we are told by de Forest, to mean that by other simple adjustments the frequency of the oscillations could be varied at will." This was astounding phraseology for a supposedly decisive opinion. For at the very crux of the issue—whether or not de Forest had conceived the idea of radio regeneration in observing his telephone repeater circuit on August 6, 1912—it rested the case on the inventor's uncorroborated word.

Yet, with only this one curious crack of light showing through an otherwise closely constructed opinion, the door was forever closed. Misled by the biggest corporations in radio and telephony, pressing arguments clearly contrary to scientific fact, the Supreme Court froze into legal precedent the fallacy that two different things are identical because they can be described in the same words.

The role of A.T. & T. in securing this outcome requires some examination, for from the moment Armstrong revealed the radio feedback circuit to the world this corporation turned a deaf ear to his claims. He who examines into the motives of corporations is on slippery ground, for a corporation is not a real individual but a self-perpetuating congeries of individuals organized for the purposes of business or industry. As a legal and social entity the corporation is less than two centuries old. The individuals making it up may be good, bad or indifferent. Their motives may vary and those of the corporation may vary, not only from department to department but also from day to day, according to the expediency of the moment. In this kind of corporate society, motives and morals, both highly personal matters, tend to become diffuse and lost in the omnipotent Whole. By common appraisal, A.T. & T., is one of the most efficient, able, scientific and impersonal of these new social forms.

The only motive safely attributable to corporations is the profit motive. A few economic facts therefore may illuminate the background against which A.T. & T. acted between 1912 and 1934. From 1912 to 1924 the Telephone Company had invested close to $400,000 directly in de Forest's patents and many millions more in research and development on the vacuum tube. Up to 1926 it was engaged in a struggle for power, based on these patents, against the so-called Radio Group—G.E., Westinghouse and R.C.A. By 1924 it was crystal clear that the regenerative circuit was the controlling invention dominating all radio broadcasting, international and

transcontinental wireless, long-lines high-frequency telephony and many communication and other devices employing the regeneration of radio-frequency currents. And in 1924 it was also clear that, if de Forest's newly issued patents could be sustained, control of this dominant invention could be extended for at least an additional ten years. Whereas Armstrong's patent, issued in 1914, would run out in 1931, de Forest's patents, belatedly issued in 1924, would run on through 1941. The whole practical effect of the Supreme Court decisions, therefore, was to fasten on the public the burden of paying tolls to the holders of a patent monopoly far beyond its proper date of expiration.

Thus both Armstrong and de Forest and the feud between them were but pawns in a much larger engagement, completely ruthless as to the rights of real individuals. Corporations could engage in this kind of cut-throat warfare, win or lose decisions, make it up together and even later join their adversaries in coalitions against other corporations in endlessly shifting patterns. Armstrong was not built along these expedient corporate lines. In life as in science he played for keeps or not at all.

On May 28, 1934, the Institute of Radio Engineers was holding its ninth annual convention in the Hotel Benjamin Franklin in Philadelphia, when Howard Armstrong walked into the meeting where nearly a thousand engineers were assembled. Their eyes glanced and turned away, as men's eyes involuntarily turn away from a man who has been set upon and beaten by overwhelming forces. His mouth was drawn and his neck and shoulder twisted in the tic he had borne since childhood. He had informed the Institute that he was going to return its Medal of Honor awarded to him in 1918 for the discovery of regeneration. He had a neatly composed speech in his pocket, a speech that in the stress under which he was laboring had taken a curiously poetic turn. It began:

"It is a long time since I have attended a gathering of the scientific and engineering world—a world in which I am at home—one in which men deal with realities and where truth is, in fact, the goal. For the past ten years I have been an exile from this world and an explorer in another—a world where men substitute words for realities and then talk about the words. Truth in that world seems merely to be the avowed object. Now I undertook to reconcile the objects of these two worlds and for a time I believed that that could be accomplished. Perhaps I still believe it—or perhaps it is all a dream . . ."

But the speech was never delivered, for the Institute's president Charles M. Jansky, Jr., began almost at once to address him directly from the chair.

"Major Armstrong," he said, "by unanimous opinion of the members of the Board, I have been directed to say to you:

"First: That it is their belief that the Medal of Honor of the Institute was awarded to you by the Board in 1918 with a citation of substantially the following import, namely, 'That the Medal of Honor be awarded to Edwin Howard Armstrong for his engineering and scientific achievements in relation to regeneration and the generation of oscillations by vacuum tubes.'

"Second: That the present Board of Directors, with full consideration of the great value and outstanding quality of the original scientific work of yourself and of the present high esteem and repute in which you are held by the membership of the Institute and themselves, hereby strongly reaffirms the original award, and similarly reaffirms the sense of what it believes to have been the original citation."

The meeting gave the inventor a standing ovation. Thus the top body of electronic engineers in America reaffirmed Armstrong as the inventor of the regenerative circuit—the Supreme Court to the contrary notwithstanding. Moreover,

it was done by unanimous agreement of a board half of whose members were prominently employed by A.T. & T. and R.C.A. or their affiliated companies. These men had lived through the founding of the radio industry and understood its scientific ramifications. They were not to be diverted by the legal arguments of their patent departments.

No scientific text worthy of the name was ever to credit anyone but Armstrong with the invention of the regenerative circuit, the start of modern radio. Other texts were to appear, however, in the realm of popular or politico-economic histories of radio, which were not so scrupulous. If they mentioned such an episode as the I.R.E.'s reaffirmation of Armstrong at all, it was relegated to a footnote—as if this episode, unparalleled in the history of American science and invention, were of no importance or had only a curious interest. The scientists were relegated in this industrial society to a position of talking only to themselves.

The situation grew ever more extraordinary with the years. On one side were the legal decisions. In twelve separate decisions made on the regenerative invention, excluding the final Supreme Court opinion (including three in the U.S. Patent Office and nine in courts of law), six tribunals decided in favor of Armstrong and six in favor of de Forest, so that there was at least a division of opinion even on the legal level, though Armstrong lost the final decision. On the other side were the engineering and scientific societies of the world, which one after another as the years went by rejected the final Court decision and affirmed Armstrong with honors as the inventor of radio regeneration. These societies included not only the top electrical engineering and scientific bodies of the U.S. but also those of England and Europe. Perhaps the highest of the U.S. awards was the Franklin Medal in 1941. In the investigative report accompanying this award, the Franklin Institute had this to say about the crucial set of experiments in 1912: "De Forest had been trying to use

his audion as a telephone repeater and the oscillations produced a howl, which rendered his circuits useless for this purpose. He, therefore, set out to get rid of the oscillations, whereas Armstrong had found out how to put them to good use. It is generally conceded by the radio engineering fraternity that de Forest was endeavoring to suppress the unwanted oscillations which occurred in his apparatus, while Armstrong, understanding the nature of the phenomena, was working to control and make use of these continuous oscillations." De Forest received many honors, including the Franklin Institute's Cresson Medal, for invention of the triode tube, but never a one for the regenerative circuit.

Meanwhile, however, the Supreme Court decision stood, immutable, irrevocable and infallible in the eyes of the uninformed. To Armstrong it was a mortal injury never allowed to heal, for it was periodically to be reopened by the legal forces of the corporations in attacks on "the discredited inventor." For these forces to admit for one moment that Armstrong was really the inventor of radio regeneration would have been to admit that a violent miscarriage of justice had taken place. Hence Armstrong's reputation had to be subtly destroyed, root and branch, while de Forest's was built up as the "Father of Radio." From the propaganda mills which modern corporations run as efficiently as do modern states the suggestion was put out on all suitable occasions that Armstrong was not really the inventor of anything. Between the millstones of the modern industrial state, the inconvenient stubborn individual had to be ground, if possible, to a grain of dust.

In the files that Armstrong kept throughout his life, preserving every scrap of paper with any markings of intelligence on it, one scrap appears in three or four versions, all in his own handwriting, without beginning or end. Whether the words are from a letter, a note, or from something he had read is not internally indicated, nor is the date.

"Think of that," the scrap reads. "Observe how much a reputation was worth in such a country. These people had seen me do the very showiest bit of magic in history, and the only one within their memory that had a positive value, and yet here they were, ready to take up with an adventurer who could offer no evidence of his powers but his mere unproven word."

Chapter 11

The FM Comeback

THIS TEN-YEAR ORDEAL, in which the foundations of his life were battered by forces new yet old in history, might have engulfed Howard Armstrong in black despair but for one thing. Parallel with all the shattering blows that were denying to him his first invention, he was bringing to flower his third major invention, destined to round out a career of creative force and intensity hardly to be matched in these times.

He would show them whether he was an inventor or not. If he could not beat them at the legal game, he would beat them in a higher game at which the corporations, for all their massive funds and elaborate shiny laboratories, showed little or no aptitude—the conception of original ideas. Now forty-four and completely bald except for a friar's fringe at the back of his head, growing portly but still powerfully active on the tennis court and in the laboratory, he launched into an entirely new development at an age when most men not only begin to slow down but become less and less capable of embracing new ideas. What made it the more remarkable was that he still had a large fortune on which it would have been easy to recline and let the world go by—the great perfidious world, always so ready to stab and to oppose, and even then rolling in the trough of the longest, hardest and most irrational depression of modern times. But to retreat from the battle was not only foreign to his nature, it never occurred to him.

On the day after Christmas, 1933, four patents filed sepa-

rately between July, 1930, and January, 1933, were simultaneously issued to him on a new radio signaling system. There were to be no gaps this time, if he could help it, through which interference proceedings might be instituted to deprive him of his invention. He had a new firm of patent lawyers, Moses & Nolte—Albert Nolte being an old friend of early Columbia days—and together they had drawn up a tight series of applications and guided them through the Patent Office so that they all issued on the same day, bearing consecutive numbers from 1,941,066. Thus by the time the Supreme Court handed down its final decision against him in 1934, he had in his pocket a sheaf of patents on a new invention that was to be almost as revolutionary in its effects over the standard method of radio broadcasting as regeneration was over all previous means of wireless communications. No one paid much attention to the new patents. Yet what the old artificer had quietly incorporated in these patents was a solution to the last basic problem in radio, the elimination of static, by a method entirely new and dazzling in its technical virtuosity.

This problem had been the first one to engage him after his graduation from Columbia and joining Pupin as assistant. It was a problem that had been with wireless from the beginning, ever-present, nagging and seemingly irremediable. Many brilliant minds had tangled with it, only to give it up. Many ingenious devices had been tried, only to fall back on the only palliative that the radio industry could seem to find for most of its chronic technical ills: more power in transmitters in an attempt to drown out atmospheric and other disturbances. But the disturbances still kept breaking in. Pupin and Armstrong floundered almost as badly as other investigators. Pupin had an idea that a negative resistance in the transmitter plus a high positive resistance in the receiving antenna might wipe out static in the system, and he set Armstrong to work building a vacuum-tube generator

to try it. It didn't work. Armstrong had ideas of his own. One of these, sketched and witnessed on a slip of paper in June, 1914, reads: "Receiving apparatus with arrangements for eliminating static by means of a revolving field caused by the interaction of the incoming signal and a local current of different frequency." It didn't work either. A veritable blizzard of small slips of paper on which he noted circuit ideas was strewn through these years. By 1922 both Pupin and Armstrong had tried everything they could think of and, disheartened, they decided to abandon the project, at least temporarily.

"The biggest problem that I can see," Armstrong said in an interview in 1922 just before leaving for France, "is the elimination of static. That is a terrific problem. It is the only one I ever encountered that, approached from any direction, always seems to be a stone wall. I suppose, however, that static will be done away with, sometime."

When he returned to the laboratory and to many more immediate problems, he still continued to think about it. He could never really abandon a project. He was working independently of Pupin now, though the bond between them was closer than ever. Soon he was proposing and trying other means of static elimination. One of these, a proposal that two receiver circuits be used, one to buck static out of the other, was demolished with a mathematical flourish at an I.R.E. meeting by a noted A.T. & T. scientist and engineer named John Carson. Armstrong said nothing but plodded silently on in pursuit of his prey. As late as 1927 he was still in pursuit in darkness, though an instinct told him that he was now on the right track. He presented a paper to the I.R.E. in that year proposing a scheme—also in the end unworkable—which would send out two waves of slightly different frequency in rapid alternation, so that static bursts would tend to interfere with only one or the other. In the

idea of somehow modifying the sending wave there was the germ of a solution.

Altogether, in the nearly twenty years that he pursued the problem, Armstrong chased, as he later expressed it, "more will-o-the-wisps than I ever thought could exist." The problem was surrounded not only by a dense bramble of technical difficulties but also by a thick fog of mistaken knowledge piled up over the years, which was often harder to get through than any wilderness. It was 1925 before Armstrong began to catch a glimpse of the real problem, which was far more deep-seated than anyone supposed. Mere gadgets, filters or circuit devices, superimposed on the broadcasting system, could never solve this problem. Nothing less than a radical change in the broadcasting system itself could get at the roots of the trouble. The wild glimpse of a solution that he saw in 1925 was that the effects of static could be overcome only by employing a radio wave different in character from the electrical waves that static produced.

The solution that eventually came out of this clear view of the problem illustrates better than any of his previous achievements the subtle, daring and tenacious mind of a great inventor. Whereas his previous inventions were made with a seemingly effortless swoop upon observations missed or not even arrived at by others, this one was made by a much longer, more complex process. Armstrong here sat down before nature and his apparatus and, slowly and painfully stripping his mind of error, followed wherever nature and his experiments led him. It took a rare patience and humility of spirit to pursue such a course through the battering years that marked his middle life. Yet nature, he knew, yields nothing worth having to force, but only to understanding.

Understanding began with static itself. This was not an ingredient generated by malevolent spirits to bedevil poor radio operators, but a natural phenomenon in the atmos-

phere in which radio operated. As early as 1915 Armstrong had conducted a series of experiments proving to his own satisfaction, and contrary to previous theory, that the bulk of all natural electrical disturbances was produced by waves varying in amplitude or power just like the modulated waves of radio itself. Hence lightning and other electrical discharges surging around the great electromagnet of the earth could easily break into and mix with radio waves to produce those crackling and crashing noises known as static. It was futile to try to blanket or exclude these discharges by brute force (i.e., more power in transmitters), for one lightning bolt could far overtop any power that puny man could put into a transmitter. It also was futile, as he laboriously found out, to try any other half-measures. On any standard broadcasting and radio receiver terms, static was ineradicable. Any device that passed amplitude variations, passed static.

Here all investigators came to a dead-end, for there was little more to be done. There was only one other characteristic of a radio wave besides amplitude that could be significantly modulated or varied, and that was its frequency—the number of complete wave cycles or undulations passing a given point per second. (There is a third form of modulation known as phase modulation, but it need not concern us here.) Frequency modulation had been tried many times in radio over the years, and all the textbooks pronounced it useless for the transmission of intelligence. But Armstrong was never bound by textbooks. Where the signs "Impassable" and "Keep Out" were thickest, there he liked to plunge in to see for himself. In 1925, along with other ideas on which he was working, he began a fresh exploration of frequency modulation. By 1932 he saw a revolutionary way to employ this method of modulation not only to eliminate static, but also to provide, contrary to all the textbooks, a system of broadcasting superior in sound reproduction and

in many engineering features to the system of amplitude-modulation radio in use for over thirty years.

Now, frequency modulation, as Armstrong pointed out in the first paper on the new system, was not new in itself. Indeed, it was inherent in electromagnetic waves from the moment such waves existed in nature. The first but unsuccessful attempt to employ it was in the Poulsen-arc transmitter around 1903. Many more research attempts were made on both sides of the Atlantic following the introduction of the vacuum-tube oscillator in 1913. But by this time a large body of mathematics had grown up governing the transmission of radio waves, and taking this mathematical superstructure for law, all investigators had made the mistake of treating frequency-modulated waves in the same way as amplitude-modulated ones. It had been found that amplitude-modulated waves moved most efficiently through space, with a minimum of interference and a maximum of clarity and economy, when they were held to as narrow a band of fixed frequencies as possible. The dictum was that radio waves should be as sharp as a knife; i.e., so "sharply tuned" that stations came in at a hairline point on the receiver dial. When, however, frequency-modulated waves were held to as narrow a band of frequencies as possible, nothing came through but horribly distorted tones. Hence it was concluded that frequency modulation was wholly unsuitable for intelligible radio communications.

Again Armstrong took up a technique regarded as of little value and transformed it into a new communications system of great beauty and utility. He did this by setting out, as in his early experiments on the vacuum tube, to investigate frequency modulation more thoroughly than anyone had done before. Apparatus for producing frequency modulation had been crude and unreliable. The Major therefore set out to develop, for the first time, a transmitter and receiver system that would give as nearly perfect, controllable and meas-

urable a form of frequency modulation as could be achieved. Even with this near-perfect system, however, he discovered that, up to a point, the textbooks had been right. Frequency-modulated waves, treated like amplitude-modulated ones, would not work. It was at this point in 1932 that he conceived his revolutionary idea, going against all orthodoxy. Instead of transmitting his waves over a narrow band of frequencies, he would allow them to swing over a very *wide band* of frequencies. When he did so, he found that frequency modulation became capable of transmitting intelligence with a clarity and a lack of distortion and interference unknown in amplitude modulation. Thus by a combination of new apparatus, without which such results could not have been obtained, and a new idea, Armstrong created an entirely new radio system.

The great irony of the situation was that most of the early unsuccessful work on frequency modulation had been done in the laboratories of A.T. & T. and R.C.A., which had come to the conclusion that it was useless for radio purposes. Most of this work was aimed at crowding more stations into the narrowest possible frequency bands. By a still greater irony, it was A.T. & T.'s John Carson, the same who had overthrown one of Armstrong's earlier ideas, who in 1922 administered what was thought to be the *coup de grâce* to frequency modulation in a paper before the I.R.E. This was an extremely able paper and mathematically sound, but Carson was so injudicious as to draw the sweeping conclusion: "This type of modulation inherently distorts without any compensating advantages whatever." Following Carson, other mathematicians here and abroad wove even more intricate proofs that frequency modulation was useless. Like the previous erroneous theories of vacuum-tube operation, these "proofs" had the effect of veiling frequency modulation's real worth from investigators.

Armstrong never allowed Carson to forget this bloomer.

Actually, Armstrong's own early experiments with frequency modulation had confirmed the correctness of Carson's calculations: i.e., *narrow-band* frequency modulation was unsuitable for radio purposes. But behind Carson stood the immense authority of A.T. & T., and Armstrong, still smarting from his defeat before the Supreme Court at the hands of this corporation, never lost an opportunity to rub it in that the investigation of frequency modulation had been fumbled. This combativeness did not make life smoother. Indeed, if Armstrong had set out deliberately to make an invention to annoy his corporate antagonists, he could not have found a more infuriating one than wide-band frequency modulation, or FM for short.

Armstrong's lifelong quarrel with mathematicians came to a head in this development. No sooner was the actuality of his newest feat digested—only some years after its first public demonstration—than the mathematicians busily erected another edifice of equations to prove that wide-band FM would work, after all, and that it did, indeed, eliminate static, as Armstrong demonstrated. This was useful for future engineering development, but it contained no reference to past mistakes and it implied in many weaseling phrases that a mathematician might have worked it all out on the back of an old envelope, if he had been of a mind to. This kind of sophistry reached so high a point that Armstrong finally wrote one of his best and most scathing papers on it, entitled "Mathematical Theory vs. Physical Concept." In it he cited names and texts, before and after his discovery, and used FM to point the fact that this invention, like all the major inventions in radio before it, was based not on a manipulation of mathematical formulae but on experiment and physical reasoning.

"The invention of the FM system," he wrote, "gave a reduction of interfering noises of hundreds or thousands of times. It did so by proceeding in exactly the opposite direc-

tion that mathematical theory had demonstrated one ought to go to reduce interference. It widened instead of narrowed the band. And it employed a discarded method of modulation which also, in learned mathematical treatments, had been demonstrated to be totally useless or greatly inferior to amplitude modulation.

"The student, picking up a text book or some analytical treatment of FM, does not get this picture. He finds, instead, a series of mathematical expressions almost totally divorced from any basis of physical reasoning. He gets the impression that he must learn to think in terms of trigonometrical functions, reams of calculations and tables of all sorts. Nothing could be more fantastic . . . the impression has been created that in some magical way invention is connected with a bewildering maze of symbols and curves."

The role of mathematics in science is much misunderstood, and to understand it is important to an understanding of Armstrong's genius. Mathematics is a powerful and in some instances an indispensable tool, a tool that can lighten the work in many sciences, but one that can never be substituted for physical experiment and reasoning. All the greatest mathematicians have understood this. The story is told of Albert Einstein by his artist friend Ben Shahn, who witnessed the incident, how Einstein one day entertained a young physicist who in the heat of expounding a new viewpoint rushed to the blackboard and began filling it with intricate equations. "But my dear boy," said Einstein, "mathematics proves nothing."

In the hands of a great practitioner and scientist, mathematics may be used to forecast a new and fruitful theory, but its validity is ever subject to the repeated test of physical experiment in the real world. In the hands of small men, mathematics may become a mere cult. Indeed, there is a good deal of numbers worship in the present high fashionableness of mathematics. Armstrong, who hated all abraca-

dabra in science, never ceased to rail at this cult. The reaches of science were grown difficult and technical enough without clouding the inquiring mind and veiling it from those physical concepts by which alone science may be understood. Like all first-rate scientists, Armstrong was a profound democrat in his belief that science should be accessible to any intelligence.

The invention of FM actually showed Armstrong to be a more precise mathematical thinker in terms of the physical concepts underlying mathematics than any of his adversaries, for wide-band FM was not simply a new radio system but a new concept greatly extending and clarifying the basic laws of communications. There are many parallels in which practical discoveries preceded and gave rise to new scientific laws. Marconi three times confounded the savants of his day with great physical discoveries—the groundwave, the skywave and, in 1932, the bending of microwaves beyond the horizon—requiring a revision and expansion of basic science to explain them. An even more classic example is Faraday. While mathematicians were constructing many elegant equations leading in the wrong direction, Faraday was discovering, wholly by physical experiment and reasoning, the essential principles of electromagnetism. And it was on Faraday's physical concept of the magnetic field that Clerk-Maxwell, with warm acknowledgment, built his great mathematical theory of light and energy.

The basic concept in FM was the idea that frequency bandwidth could be traded for a higher signal-to-noise ratio, the measure of quietness in a communications circuit. Briefly, the wider the band of frequencies employed, the greater the suppression of noise or static. It could be reduced to a mathematical formula: the power gain of the signal-to-noise ratio increases as the square of the frequency bandwidth used. This concept was first revealed in Armstrong's historic demonstration of FM in 1935. The new principle revealed event-

ually caused a revision of a previous scientific law, known as Hartley's Law after the A.T. & T. scientist who had devised it, which up to then had been thought to govern the amount of information that could be transmitted over a communication system. Armstrong himself did not have the ability to see or to elaborate the mathematical consequences of his idea. But the new concept became a key element in that body of abstruse mathematics, devised chiefly by Norbert Wiener of the Massachusetts Institute of Technology and Claude E. Shannon of Bell Telephone Laboratories, known as modern information theory. This theory represents a fundamental change in the design and analysis of communication systems, freeing the engineer from previous limitations, and already it has proved a powerful new tool not only in radio, telephony and telegraphy but also in sciences as far afield as psychology. To find Armstrong and FM credited with having contributed one of the seminal ideas to this theory, one has to read foreign papers or texts in which commercial rivalries are not so rampant as in the U.S.

To go back in detail to the development of FM, Armstrong was strenuously occupied from 1928 to 1933 in getting FM into its first working form. One reason for the time consumed was the nature of the development. Whereas the invention of the feedback circuit involved only one vacuum tube, the early work on FM often required as many as 100 tubes in a single "breadboard" setup. Sometimes months were needed to set up and try one experiment. By 1933 he had made and recorded over 100,000 measurements. In addition to all this, the whole early development of FM was carried on by Armstrong alone, a feat probably unique for an invention of this size and character. There was some laboratory assistance. Tom Styles had joined him in 1924 as an assistant, secretary and general factotum, and, soon after, Armstrong took on another early friend from Yonkers, John

Shaughnessy, to help build apparatus. But the burden and the direction were Armstrong's.

Pupin was ailing all through the latter part of this time and lived only long enough to see his old project of static elimination in the first stages of accomplishment. Pupin died on March 13, 1935, at the age of seventy-seven. Armstrong had been appointed a full professor the year before and his name was promptly proposed by influential friends of Pupin, including Gano Dunn, a distinguished electrical consultant and financier, to take over Pupin's chair at the head of the Marcellus Hartley Research Laboratory. Armstrong was appointed with a glowing letter from Nicholas Murray Butler, President of Columbia University, warmly paying tribute to his inventive genius and to the continuing glory that it brought to the school. Mixed with the sadness of Pupin's passing, this was one of the proudest moments in Armstrong's life. Typically, he left unchanged every item in Pupin's paneled office, Room 206 in the basement of Philosophy Hall, even down to the old Edison carbon-filament lamps in the wall brackets. His own status remained practically unchanged, a nominal salary of $1 a year, which he never collected, and the freedom to do research as he pleased in the oldest tradition of great universities.

All the original research and development of FM was carried on in the old basement laboratories of Philosophy Hall. Long tables bore the neat but intricate clutter of electronic circuits spaced out for precise experiments. They were surrounded by a maze of measuring apparatus and the glinting fronts of high, old-fashioned glass cases packed with still more apparatus. Armstrong, in a private arrangement with the university, supplied all funds for equipment and assistants' salaries, and bore all overhead expenses beyond the bare maintenance of working quarters, power and light. The laboratory was run with loose informality in that vital disorder in which most creative work is done, an atmosphere sharply

different from that surrounding most industrial research, yet with strict regard for the object in view.

To work for Armstrong, as one of his later assistants put it, was no bed of roses. Work followed the rhythm of the task in hand, relaxed sometimes for weeks and months when Armstrong barely appeared in the laboratory, intense when he was closing in on a problem. Through most of the years between 1928 and 1934, when FM was being developed, laboratory records show activity going on seven days a week and often far into the nights, and on all holidays except Christmas. Armstrong worked along with that singular absorption and detachment that, even in relaxation, never allowed his mind to cease from turning over the problems with which he was grappling. He lived plainly, even austerely. He would wear the same necktie day after day until it frayed away and shoes until they were out at the soles. His luncheon invariably consisted of a cheese sandwich and a glass of milk, taken hastily in a small shop on Amsterdam Avenue. Tom Styles, who liked more leisure and variety, once got him into a French restaurant. Armstrong, to mark the occasion, blandly ordered two cheese sandwiches and a glass of milk. In his working life, however, there was never any lack of excitement and variety. Nearly every task he directed pressed forward into regions where no man had trodden before.

In the development of wide-band FM it was frontier all the way, involving a dexterous interplay of sender and receiver to create a new radio system. Basically the problem was to send out from the transmitter a new type of radio wave, the exact opposite of the amplitude-modulated waves long in use, in which the amplitude or power, instead of being varied, was held constant while the frequency was rapidly varied over a band of frequencies 200,000 cycles (200 kilocycles) wide to carry the sound-pattern variations of the human voice or music. The FM wave, instead of being variable in crest or depth, was variable only in the number of

wave cycles passing a given point per second. The transmitter which Armstrong worked out, embodied in one of the patents issued to him in 1933, was part of the earlier apparatus he had devised to produce a more precise and controllable form of frequency modulation than any theretofore. It employed a highly stable crystal-controlled oscillator or transmitter whose waves were modulated by what is known as phase shift. The wider the frequency swing of the waves thus produced, the less did natural static or noise, narrow in frequency, impinge on them.

The key to the system was the receiver which Armstrong devised to accept this new type of radio wave and translate its frequency variations into amplitude variations and thence into sound at the loudspeaker. Until this special receiver was developed, embodied in another of Armstrong's basic patents of 1933, there were no precise methods for receiving frequency-modulated waves. It was another display of Armstrong's genius for electronic circuitry. The basis of his new receiver was the superheterodyne circuit, to which he added two special circuit stages that were the key to FM reception. In the first stages of this receiver the incoming FM waves were heterodyned down to an intermediate frequency and amplified, just as in any superheterodyne set. The amplified waves then passed to a special vacuum-tube circuit called a *limiter,* which in effect clipped off any amplitude variations (static) the waves might have acquired en route or in the receiver itself. The purified signal then went to a circuit known as a *discriminator,* which converted the original frequency variations into amplitude variations, ready for detection and amplification by the usual final stages of a superheterodyne receiver. In other words, after all possible extraneous noise was strained out of the FM wave, it was translated to amplitude modulation and then into current at audible frequencies to activate a loudspeaker.

From transmitter to receiver, therefore, Armstrong in-

vented a kind of "closed circuit" in space for a new type of radio system. It propagated a wave not easily broken into by static or random noises, and it provided a special receiver that rejected any such noise that did break in and accepted only the frequency pattern of the original signal. Some man-made static, such as that put out by diathermy machines and aircraft engines, could still break in, but this was only a minor part of the static problem. The FM system eliminated nearly 99 per cent of all static effects, a feat unparalleled in the history of communications. The first public demonstration of this system was made when Armstrong presented his classic FM paper—entitled "A Method of Reducing Disturbances in Radio Signaling by a System of Frequency Modulation"—before a large meeting of the I.R.E. in the auditorium of the Engineers Building on 39th Street in New York on the evening of November 5, 1935. This was nearly two years after Armstrong's basic patents were issued, and the reason for the long delay will later appear.

To put on the I.R.E. demonstration, which was in the nature of a surprise, Armstrong enlisted the aid of his old friend Randy Runyon, who was still a coal company executive by day in Manhattan but a fervent radio amateur by night in Yonkers. Together through the summer of 1935 they toiled to rebuild Runyon's amateur station W2AG to operate on FM at 110 megacycles—Runyon building the power end of the transmitter in his attic, Howard the modulator and the receiver in his laboratories. To get sufficient radiating power at these high frequencies was no easy task, for no special power tubes were then available and no FM transmitter had ever been built in those frequencies before. When it came time to run the first long-range test of the new transmitter, a freak incident nearly caused them to abandon the whole project.

For this test, Armstrong took the receiver down to the Runyons' summer home on the Jersey shore at Mantoloking

one weekend. The transmitter in Yonkers was beamed directly at Mantoloking, and Armstrong had a highly directional FM aerial which he and Runyon carefully oriented on the chimney of the beach house, with running comment from Johnny Grinan, who happened to be a weekend guest. But no amount of fiddling with the hook-up brought in more than a weak signal, and the search for the trouble went on until eleven that night. At this point, Armstrong, with characteristic energy, announced that he was going to run the set back to his Columbia laboratory for a thorough bench test and would be back for breakfast in the morning. After an all-night session that found nothing wrong with the receiver, he was back in Mantoloking bright and early the next morning. But still reception was no better, and they lugubriously began to conclude that there was something unsuitable about the 110-megacycle range for FM. Grinan suggested as a last desperate measure that they twist the aerial about. When it was rotated about thirty degrees—promptly dubbed the "Grinan angle"—Yonkers suddenly came in with a volume that nearly blasted them out of the house. Two leads had been accidentally reversed in building the aerial, giving it a pick-up pattern different from the one intended. This accident might have caused them to abandon all work in the 110-megacycle band, where FM later was to find some of its most important uses.

The final tuning and testing of the Runyon transmitter was completed only half an hour before the I.R.E. meeting in November. Armstrong stood at the lectern, delivering his paper, giving no hint of the coming demonstration. George Burghard sat in a wing, behind which the receiver was hidden, with Paul Godley at the controls. Just as the paper was leading up to the vital point, Burghard stepped up to the lectern with a note: "Keep talking. Runyon has burned out generator." Mrs. Armstrong and Mrs. Burghard, who were in the audience, tensed. Without batting an eye, the Major

blandly continued until he finally received a signal that all was ready again. "Now, suppose we have a little demonstration," he drawled. For a moment the receiver groped through the soughing regions of empty space, roaring in the loudspeaker like surf on a desolate beach, until the new station was tuned in with a dead, unearthly silence, as if the whole apparatus had been abruptly turned off. Suddenly out of the silence came Runyon's supernaturally clear voice:

"This is amateur station W2AG at Yonkers, New York, operating on frequency modulation at two and a half meters."

A hush fell over the large audience. Waves of two and a half meters (110 megacycles) were waves so short that up until then they had been regarded as too weak to carry a message across a street. Moreover, W2AG's announced transmitter power was barely enough to light one good-sized electric bulb. Yet these shortwaves and weak power were not only carrying a message over the seventeen miles from Yonkers, but carrying it by a method of modulation which the textbooks still held to be of no value. And doing it with a life-like clarity never heard on even the best clear-channel stations in the regular broadcasting band.

The demonstration that ensued became a part of the Major's standard repertoire in showing off the remarkable properties of his new broadcasting system. A glass of water was poured before the microphone in Yonkers; it sounded like a glass of water being poured and not, as in the "sound effects" on ordinary radio, like a waterfall. A paper was crumpled and torn; it sounded like paper and not like a crackling forest fire. An oriental gong was softly struck and its overtones hung shimmering in the meeting hall's arrested air. Sousa marches were played from records and a piano solo and guitar number were performed by local talent in the Runyon living-room. The music was projected with a "liveness" rarely if ever heard before from a radio "music box."

The absence of background noise and the lack of distortion in FM circuits made music stand out against the velvety silence with a presence that was something new in auditory experiences. The secret lay in the achievement of a signal-to-noise ratio of 100-to-1 or better, as against 30-to-1 on the best AM stations.

The I.R.E. demonstration had curiously few repercussions in the radio world. To begin with, an improvement to 100-to-1 in signal-to-noise ratio was frankly unbelievable. Anything approaching this in orthodox AM radio was quite out of the question. Armstrong was not satisfied with a 100-to-1 ratio, and he shortly succeeded in raising this to 1,000-to-1. But by all the rules that had been drilled into radio engineers for nearly a quarter of a century this was even more fantastic.

The advantages of FM over AM were not to be digested in a night. They were tightly bound up in the complexity of the new principle, one advantage following another in that closely knit pattern that marks the protean aspects of a great invention. Because the amplitude of the carrier wave was kept constant, FM transmitters required much less power than AM stations for covering a given distance. Hence FM was initially more economical than AM. Because power was held constant, an FM station needed no monitoring as in AM, where a "gain rider" had to be ever on the alert to turn down the power whenever any loud tone threatened to raise amplitude to a point where it overloaded the circuits and blasted the station off the air. Because FM could take the loudest or softest tones without such distortion and modulate them over a wide band of frequencies, it could transmit the full frequency range of sound and music in a way that was practically impossible on AM. Whereas regular AM stations, crowded in the longwave region of the radio spectrum, were forced to cut off all tones above 5,000 cycles, FM had a usable range of 15,000 cycles capable of carrying all the overtones that give life, sparkle and naturalness to sound and music.

Because FM required a wide band of frequencies, it was designed to operate in the relatively unused shortwaves, where static is less and high-fidelity transmission becomes feasible. This opened a new region of the radio spectrum to broadcast development, where many more frequencies were available and many more stations were possible than in the limited longwaves. Thus FM, designed as a system to eliminate static, presented itself also as a system peculiarly suited to the high-fidelity transmission of sound and to a wholly new development of aural communications.

Only a few engineers present at the demonstration in 1935 caught fire at the prospects. For the most part the reaction was subdued. For one thing, this was something entirely new in engineering experience. There were no FM stations on the air and no FM receivers—and no point in building receivers until there were stations to listen to. FM presented a lock-and-key problem quite unlike anything previously known in radio. For another thing, theory held that the very shortwaves were limited to a range bounded by the line-of-sight from the transmitter, a matter of twenty or thirty miles at best, which seemed to indicate that FM would have only limited coverage. Both Marconi and Armstrong had proved that this was not so, but the theory hung on. In addition to this, there was the matter of FM band width. To engineers trained for years in making the most economical use possible of radio frequencies, FM's use of frequencies seemed profligate. In the frequency space occupied by just one FM station five ordinary AM stations could be placed. There were many mitigating factors that made this comparison wholly meaningless, but they were not immediately apparent. Finally, the biggest fact to give engineers pause was that FM proposed an entirely new radio broadcasting system to be superimposed on and eventually to supplant the existing one, then less than fifteen years old. To engineers, generally conservative by nature, any such sweeping changes

were to be viewed with utmost caution if not downright skepticism.

Nevertheless, with the invention of wide-band FM, Howard Armstrong clearly demonstrated again to the world that he was an inventor and scientific innovator of a high order. There was to be no shadow of a doubt cast on this invention, though well over a decade later there would be those who would try. It was, in fact, an invention of such a disruptive kind as only an obstinately independent intellect could have made. It did not fit into the commercial scheme of things. It proposed, in fact, the overthrow of a very large investment in AM broadcasting and of the whole technical pattern by which a few corporations had come to control all radio. It was not an invention that a worker in the big industrial laboratories would have been likely to conceive, or having conceived, would have been allowed to develop freely or rapidly. The corporations were—in the gleeful phrase Armstrong had applied as a youth to his tripping of the visiting professor of physics—"shown up for sure." Armstrong was so many years ahead of the industry and everyone else in his conception of FM that he was confronted by a novel situation. Whereas his previous inventions had been taken up with reasonable alacrity by an industry just getting started, he was now faced in FM with a long, hard struggle merely to get its basic concepts accepted.

Chapter 12

The Defender of the Human Ear

THE PLAIN SITUATION that faced Armstrong in the autumn of 1935, as he made his demonstration before the engineers, was that the radio industry, at least as represented by its leading corporations, wanted no part of his new invention. Some of this resistance may be attributed to sheer inertia and an inability to see its significance, but more is attributable to something else. However superior and ingenious the FM system might be over ordinary AM broadcasting, it was in its basic concept much too disruptive of the settled pattern of the industry to be accepted or even given a hearing without a long, expensive and bitterly fought battle in which the inventor himself had to carry his new radio sytem to the public.

In the best of times inventions of this nature have difficult going, but this was the Thirties, when the country was gripped by a paralysis of now almost unimaginable proportions. The nation was only slowly emerging from the Great Depression, destined to linger on through the decade. President Franklin D. Roosevelt had come to office in 1932 and the clash of reform and recrimination was still filling the air. Business, preoccupied in trying to hold on to what it had in shrinking markets, was loath to risk anything on new ventures. Economists searched in vain throughout the decade for a new industry, such as the automobile and radio had provided in the Twenties, to carry the country forward to new growth. The general opinion was that industry had grown

too fast—"over-production" was the word on every analyst's lips—to assimilate new ventures. Yet for lack of such ventures, idle machines were matched by idle men.

Radio had grown up more rapidly than almost any other industry before or since. On the wings of Amos 'n Andy, the A & P Gypsies, Wayne King waltzes and other trivia too numerous to mention, interspersed with a few astonishing extensions of human culture and communications, the radio industry had risen by 1935, even through the dark of the Depression, to a half-billion-dollar-a-year industry whose pattern had been settled a decade before. In the stratification and control of that industry, as much as in anything else, lay some of the inflexibilities in dealing with the Depression from which the country was suffering.

The radio industry's structure had coalesced, with some changes at the top, into a familiar pattern. In 1926 A.T. & T. had sold its key station WEAF to R.C.A. for $1 million and, with only a few hankering backglances, retired from radio. The old Agreement of 1919-1920 was revised to define the new spheres of interest between A.T. & T., which retained radiotelephony and exclusive rights to provide the wire services linking cities together in radio network broadcasts, and the Radio Group, still composed of R.C.A., General Electric and Westinghouse. R.C.A.'s President David Sarnoff promptly proceeded, on the acquisition of A.T. & T.'s broadcasting interests, to set up the National Broadcasting Company—a company 50 per cent owned by R.C.A., 30 per cent by G.E. and 20 per cent by Westinghouse. This new company linked forty-eight powerful stations in key cities into three networks, the Red, Blue and Pacific, destined to dominate broadcasting from coast to coast. In 1927 the competitive Columbia Broadcasting System had its birth, out of the old Columbia Phonograph Record Company, through acquisition by a Philadelphia group headed by William S. Paley. Later, one of N.B.C.'s networks was detached by government

order to form the independent American Broadcasting Company. Only one other national network was destined to be independently established, the Mutual Broadcasting System in 1934.

Network broadcasting became the controlling pattern of U.S. radio. It grossed over $50 million in advertising sales by 1935 and more than quintupled that in the next decade. There were by then close to 1,000 radio stations in the U.S., but only key stations in large centers of population really counted from a mass sales viewpoint, and these were controlled by the big networks through direct ownership or affiliation. Few additional stations could be built in the limited, already crowded longwave radio band, hemmed in by other services, without degrading broadcast standards or courting interference. The restricted number of frequencies available in the regular radio band was exactly suited to the growth of the network oligopoly—the control of the business by a few large companies—for monopoly thrives on nothing so well as on natural or self-imposed restrictions.

To regulate the traffic on the restricted radio frequencies, Congress in 1927 created the Federal Radio Commission, which brought some belated order out of the early chaos. This was now superseded in a reform-minded administration by the much broader Communications Act of 1934, setting up the Federal Communications Commission to license and police, "in the public interest," not only radio broadcasting stations but all other forms of wireless and wire communications, including telegraphy, telephony, television and facsimile (wireless picture reproduction). In the broad and somewhat indistinct powers delegated to the seven-man FCC there was to be an endless source of friction and uneasiness for the private interests thus regulated. But as with all regulatory bodies, there were compensating loopholes. The commissioners were political appointees of various tenure and shifting complexion, generally without technical or practical

knowledge of the industry they were set up to regulate. Power therefore devolved largely upon the Commission's engineering and legal staffs, which, like most such staffs in government service, was ill-paid and inadequate. Finally, the issues the FCC was called upon to decide were generally of such a nature as the public found hard to understand, even if it was adequately informed or interested, which it rarely was.

Under these conditions the communications industry was never to find itself severely hampered by the FCC in getting its own way. Indeed, it found ways to use the FCC to further limit competition and increase its own powers. Whereas the industry's trade associations and leading corporations were constantly dealing with the FCC from day to day, the public rarely if ever had so intimate a contact with or representation in its workings. All such governmental regulatory bodies over the years tend to take on the coloring and viewpoints of the industries they are set up to regulate. The means of fraternizing with and influencing such bodies are many and varied, not the least being the dangling of such tangible rewards before staff members as a better job at higher pay in the industry being regulated. The new FCC was barely two years old when R.C.A. hired away its chief engineer, Dr. Charles B. Jolliffe, eventually to be vice president in charge of all R.C.A. research.

The Radio Corporation of America was by then the most potent factor in all radio. In 1930 it had bought out the radio-set manufacturing facilities at Camden and Harrison, New Jersey, of G.E. and Westinghouse, just one step ahead of a big anti-trust suit which the government finally got around to levying against the peculiar arrangements of the big Agreement. After nearly two years, the suit was settled by consent decree—a legal formula in which the accused corporations agree to certain corrective measures without admitting to any infraction of the law. Under this decree, G.E. and West-

inghouse divested themselves of all stock and direction in R.C.A. and agreed not to manufacture or sell any radio apparatus for two and a half years. The patent agreements between A.T. & T. and the Radio Group were left practically undisturbed, except for an order making licenses non-exclusive, for without this huge pooling of patents radio manufacture could not function. R.C.A. emerged from all this stronger than ever before. Not only did it own the biggest broadcasting network but it now had the largest radio manufacturing facilities. In addition, it controlled for all practical purposes the licensing of all key radio patents, upon which it had been gradually reducing restrictions and royalties, from 7½ per cent eventually to 2¼ per cent, with licenses open to all comers. The rationale behind royalty collections, which eventually rose to over $10 million a year, was that these would go to build up and finance R.C.A. research for the whole industry. By 1935 R.C.A. was at last the premier radio corporation of the country.

Meanwhile, the Depression was battering the radio industry almost but not quite as badly as any other. The manufacture of radio sets, which could be undertaken on a shoestring, had run out of hand from the beginning. By 1935 the sale of radios had reached what looked like saturation, with nearly 40,000,000 sets turned out in little over a decade. On sharply declining sales, many pioneer companies went bankrupt or retired from business. Even R.C.A. had heavy losses in 1932 and 1933. Though it was by then the largest maker of radios, R.C.A. still could not capture more than a small part of the business, which continued to be held by a host of smaller companies led by Philco, Zenith and Emerson. As competition sharpened even more in the Thirties, the average price of radios was driven down from $135 to $35 and even lower, with the bulk of all sales eventually going to small table models of generally low quality. Competition was reduced to cutting all possible corners, making minor

"gadget" improvements and essaying no basic engineering changes. This was the eroding effect of the Depression, in which engineering integrity was whittled away to a shadow.

To Howard Armstrong's sensitive ears, and to those of many other radio engineers, the sounds that came from radio sets were more and more painful. As the inventor of the superheterodyne and still one of the largest individual stockholders in R.C.A., Armstrong took an active interest in trying to uphold standards. He followed closely the company's Coordination Committee meetings at which specifications were drawn for new models, investigating them himself, offering suggestions and even working out improved designs to hold quality without unduly raising costs. In 1930 he wrote one of many letters to Sarnoff complaining of the repeated cut-backs in the number of circuit stages in superheterodynes, which he maintained had lost for the company its quality leadership, and urging settlement on a new design that would assure outstanding performance. But the time and tides were against him as the Thirties continued to run out over the economic shoals and shallows.

Such was the environment in which Armstrong was trying to press a revolutionary invention on an established industry. Later he would jocularly maintain that he had invented FM to get away from "a radio that sounded like a radio." But his first attempts to get a public hearing for his new form of radio were met with an enveloping silence and skepticism. It was one man against a strong tide of corporate retrenchment and general failure of nerve.

The saga began shortly before Christmas, 1933, when Armstrong invited David Sarnoff up to the Columbia University laboratories to witness his latest wonder. Sarnoff had often said that he was waiting for someone to come along with "a little black box" to eliminate static, and Howard invited him up to see "the little black box he had been waiting for." Moreover, Armstrong had promised with the

sale of his superregenerative circuit some ten years before to give R.C.A. first look at any new inventions he might make. And R.C.A., by reason of the large royalties it had collected and the large research laboratories these had built up, was the logical company to undertake the expensive development of a new invention for the industry. Sarnoff was interested but wary. This was not a "little black box" but a whole new radio system, filling two rooms with its transmitter and receiver apparatus. In subsequent demonstrations, R.C.A.'s top engineers witnessed the new marvel in the basement of Philosophy Hall. In March of the following year it was suggested that the equipment be moved to experimental quarters at the top of the new Empire State Building to be put through actual broadcasting tests. Mere laboratory tests of "static eliminators" were regarded with justifiable suspicion.

In the spring of 1934, therefore, Armstrong happily went about setting up his FM modulator in the Empire State Building, using as power source a 2-kilowatt, 44-megacycle transmitter already there for experimental television purposes. The FM receiver was installed in George Burghard's summer place at Westhampton Beach, Long Island, seventy air miles away. This was the same spring in which, in the complexly interwoven fabric of Armstrong's life, the Supreme Court was reaching its second fateful decision against him in the de Forest matter, with R.C.A.'s legal department ranged against him. Yet the air of preparation in the Empire State was cordial, for Armstrong had had a long professional acquaintance with R.C.A.'s engineering staff and he was still on the friendliest terms with Sarnoff. Early in the year he had sent a felicitous message to R.C.A.'s president, on winter vacation in Bermuda, reminding him that this was the twentieth anniversary of the night they had spent together in the wireless shack at Belmar, New Jersey, making the first full-scale test of the original regenerative circuit. And Sarnoff

had gracefully replied, trying to soften the court actions that were denying Armstrong his title to that clear invention.

"Dear Major," he wrote, "It was very kind and thoughtful of you to have sent me your message to Bermuda, which brightened my vacation by making me think more of the happy past than of the confused present.

"Well do I remember that memorable night at the Belmar station when, by means of your 'magic box,' I was able to copy the signals from Honolulu and other distant parts of the world. The floors at Belmar did not then seem to feel so hard and the bitter cold did not numb the fingers. Whatever chills the air produced were more than extinguished by the warmth of the thrill which came to me at hearing for the first time signals from across the Atlantic and across the Pacific.

"It would seem hard to believe that twenty years—a full generation—have passed since the night of the event we now speak of. One's natural vanity would prefer to explain this by emphasizing the youth of the wireless art, but the generous sprinkling of gray hairs that now resides on my dome and the pronounced absence of gray or black hair on your dome, alas, makes it impossible for both you and me to fervently embrace that alibi.

"And yet here you are a generation after that event, still gripped by the mystery of the air, still challenged by the secrets of space, and still in the forefront of advanced thinkers and workers in the art. These attributes are true evidences of youth, the others are but fleeting signs.

"It is not a sermon I wish to preach, but rather a hope to emphasize. If you will fix your gaze and energies upon the next twenty years and let history deal with the past twenty years, the telegrams and letters we should be able to exchange at the end of the next generation would make us feel that we

were still young even then. With affectionate regards, David Sarnoff."

But the Major needed no urging to direct his energies toward the future, though he would never forget the past, for the future was again opening out before him in the searching rays of his newest invention. The initial test from the Empire State transmitter, the first field test of his new invention, showed FM to be something even beyond his own expectations. The first morning's log at Westhampton Beach, dated and witnessed June 16, 1934, bears this prophetic and summary notation in Burghard's hand: "An era as new and distinct in the radio art as that of regeneration is now upon us."

In test after test through that early summer, reception at Westhampton Beach was recorded with utter quiet through some of the heaviest thunderstorms of the season, storms which made the regular broadcasts from New York's biggest radio stations totally unlistenable. Again, nothing like it had ever been heard before. To radio engineers who had been struggling with this problem for years, and even to radio laymen, the thunder-defying properties of FM were something phenomenal. The Westhampton site was probably too favorable, it was thought, so the receiver was moved to Haddonfield, New Jersey, into the home of an R.C.A. engineer, veteran wireless operator and longtime Radio Club friend of Armstrong's named Harry Sadenwater. And again tests were recorded with the same clarity through electrical atmospherics that had always made summer radio a crackling nightmare.

The data piled up in these tests were overwhelming and not only confirmed Armstrong's basic claims for the FM system but bettered them and extended them into areas where he had suspected hidden values without being able to put them to the test of field performance. Contrary to theory, FM's very-high-frequency transmission of signals was not

limited to the horizon but in actual measurements from the Empire State Building showed clear reception out to at least three horizons—or a distance of about 80 miles. If the transmitter were raised in power and altitude, it could probably get far beyond that. Moreover, out to the very fringe areas of reception, signals were received with a clarity and lack of fading unknown in AM. Hence the FM station actually had a larger coverage or service area free of disturbance than any regular AM station in the U.S. except a few superpower, clear-channel AM stations when static was not marring their reception. All fears that FM would have only limited coverage were put to rest. As an audacious fillip to this series of historic tests, Armstrong on November 24, 1934, performed an astonishing stunt, clearly foreshadowed in his basic patents. At one and the same time on a single FM carrier wave he transmitted from the Empire State: 1) two programs from the NBC networks; 2) a facsimile reproduction of the front page of that day's New York *Times;* and 3) a telegraph message. This was to show that FM as a basic new system was capable of linking up all types of communications.

Various groups of R.C.A. engineers went over the FM system for themselves. Various technical reports were written, some highly favorable, some cautious and adverse, all tentative as to how to accept this new phenomenon. One report dated October 9, 1935, by a group headed by Harold H. Beverage flatly stated as the result of exhaustive measurements: "Frequency modulation with a deviation of 100 kilocycles is shown as increasing the service radius from 3 to 5 times the amplitude modulation service radius." FM operating at 2 kilowatts was here being compared not only with AM operating at the same frequencies and power but also with regular longwave AM operating at 50 kilowatts of power. As these astounding results continued to pile up, there was a notable cooling and drag of cooperation from the higher echelons in R.C.A. Sarnoff was abroad through the late summer of 1934, and as soon as he returned Armstrong went in

to see him to try to get things moving. As he vividly remembered and testified to the conversation later on, it reached this point.

"Why are you pushing this so hard?" asked Sarnoff.

"There is a depression on," said Armstrong. "The radio industry needs something to put life in it. I think this is it."

"Yes," said Sarnoff, "but this is not an ordinary invention. This is a revolution."

"That is all the more reason to get it into use as fast as we can," replied Armstrong.

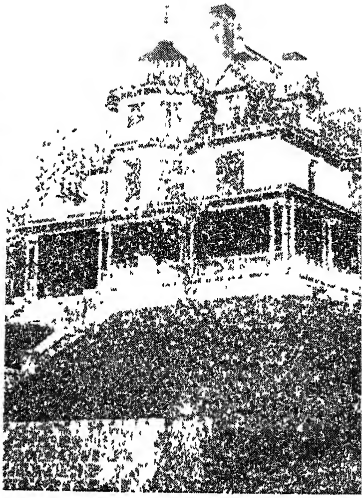
The subject was changed and Armstrong could get nothing definite out of Sarnoff as to the future of FM. Later Armstrong got him over to Haddonfield, New Jersey, for another demonstration and the path seemed to lighten. Sarnoff promised to appoint Dr. W. R. G. Baker, then vice president in charge of research and engineering and favorable to FM, to head a new committee to push both FM and television—after Baker had returned from a South American vacation. There was more delay, and when Baker returned he was not to be promoted to the new task force but "promoted" out of the company. Meanwhile, as 1935 dragged on, the engineering department called for more tests, more measurements, over and over again. Finally, in April, Armstrong was politely asked to remove his apparatus from the Empire State Building to make way for a resumption of television experiments. Armstrong withdrew in a huff, but the break did not yet seem serious. Only a month later Armstrong was on his feet at R.C.A.'s annual stockholders' meeting on May 7 defending Sarnoff from attack and praising his role in pulling the company through difficult times—even though, he added, "I have a row on with him now."

For nearly two years Armstrong had given R.C.A. an exclusive preview of his invention, and for nearly two years he had been dangled on a string. Since he had felt it incumbent on himself to keep mum about FM until R.C.A. made

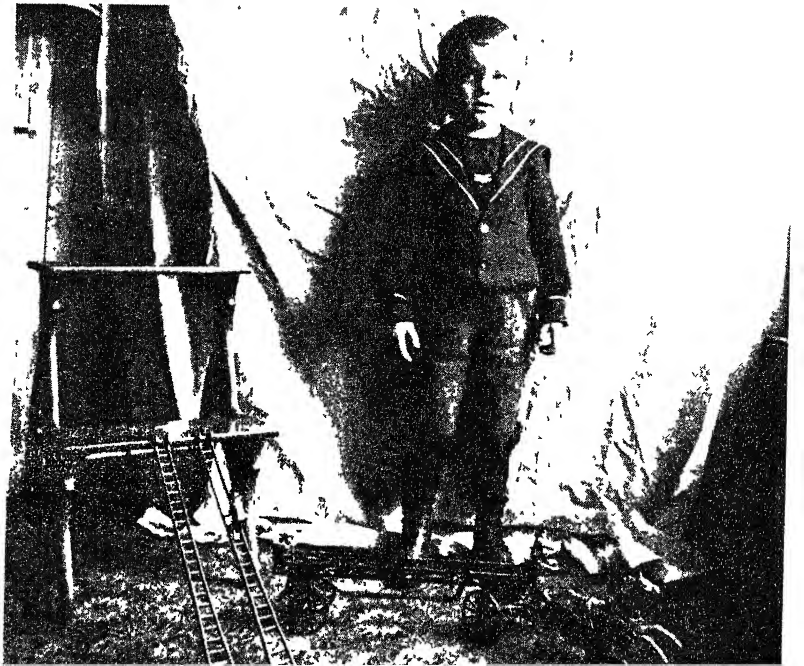
up its mind, it was late in April, 1935, before he made his first public announcement on the accomplished fact of this new method of broadcasting and prepared to make his first public demonstration before the November meeting of the I.R.E. Ten days after his April announcement, R.C.A. splashed across the nation's press with an announcement that it was ready to develop electronic television with an initial expenditure of $1 million. It made no mention of FM.

Nor was this the full extent of the curious reign of silence that was to surround FM in those crucial days. To be sure, shortly after Armstrong's I.R.E. paper, a number of R.C.A. engineers presented various papers on FM before the same body, but this was another instance of engineers talking to themselves. So far as public pronouncements on FM were concerned, the silence from everyone except Armstrong was deafening. In January, 1936, the Federal Communications Commission made its first annual report to Congress on the progress of radio and communications in 1935, with technical advances reported by its Chief Engineer Charles B. Jolliffe. There was no mention of FM. But Jolliffe's report did contain a statement to the effect that the very high frequencies (in which both FM and television operated) were of limited value because the service range in this region would be "only a few miles, probably of the order of two to ten miles." This despite proof in Armstrong's FM paper of November, 1935, supported by recordings of actual broadcasts, that transmissions over 80 miles or more had been achieved. Moreover, it was FM's performance in these frequencies that, along with other things, allowed R.C.A. to move confidently into television, which in 1935 was technically less far along than FM. Nevertheless, it was only a few weeks later that R.C.A. hired Jolliffe, for what tasks will soon appear.

Late in the spring of 1936, the FCC called upon the radio industry to supply the Commission with all pertinent information to aid it in apportioning experimental frequencies



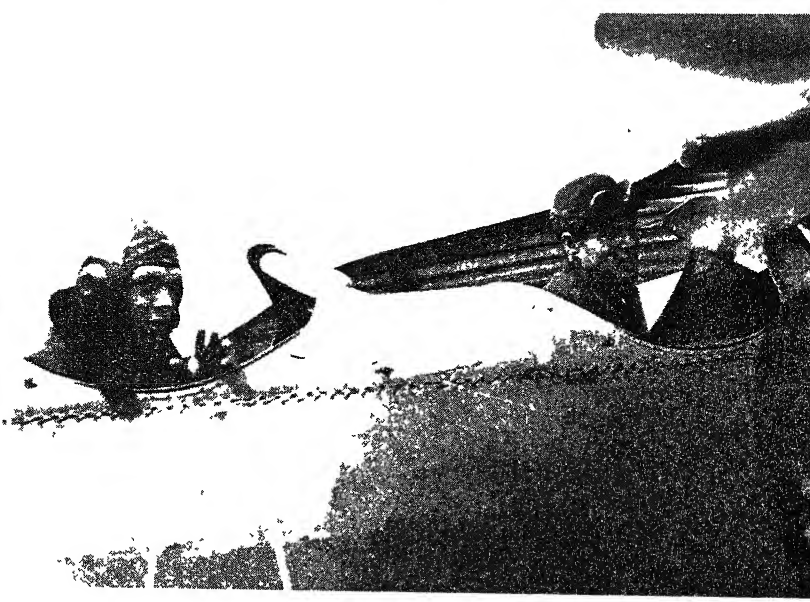
(*Left*) Edwin Howard Armstrong, age three, poses with his baby sister, E in New York City, where he was born, December 18, 1890 (*Right*) The A strongs moved in 1902 to this big house on a bluff at 1032 Warburton Ave Yonkers, where, in the attic room under the cupola, Howard began to study w less telegraphy and made his first historic invention—the feedback circuit—in I

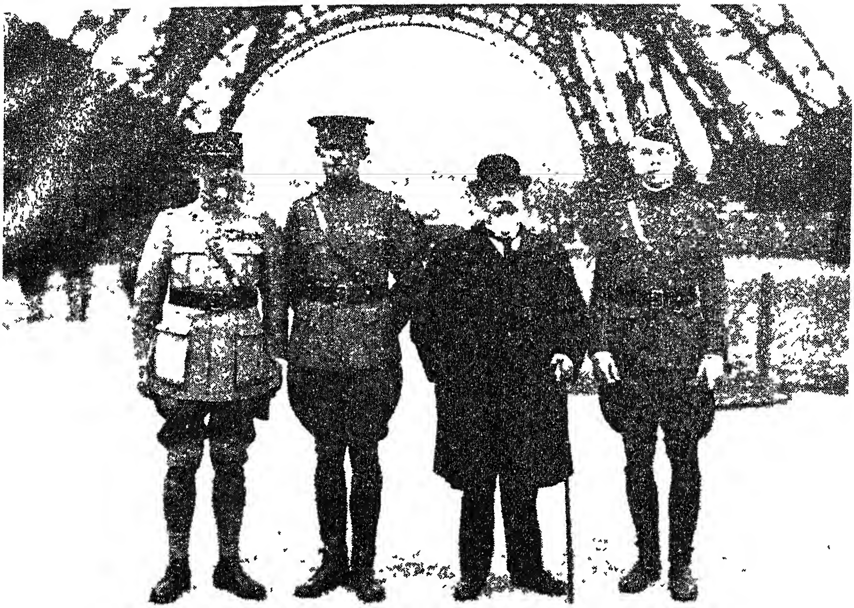


A Tennyson Beals

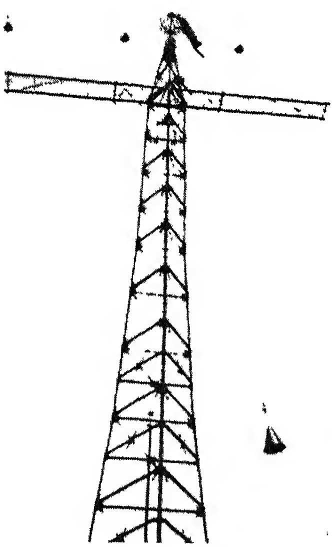
In 1917 Armstrong went to France as a captain in the U S Army Signal Corps, came out with the rank of Major and another invention, the superheterodyne, the basis of nearly all of our modern radios

In France in 1918, Armstrong (*left*), worked on the first radio communication system for the infant U S Air Force in the canvas-and-matchstick flying machines of that day





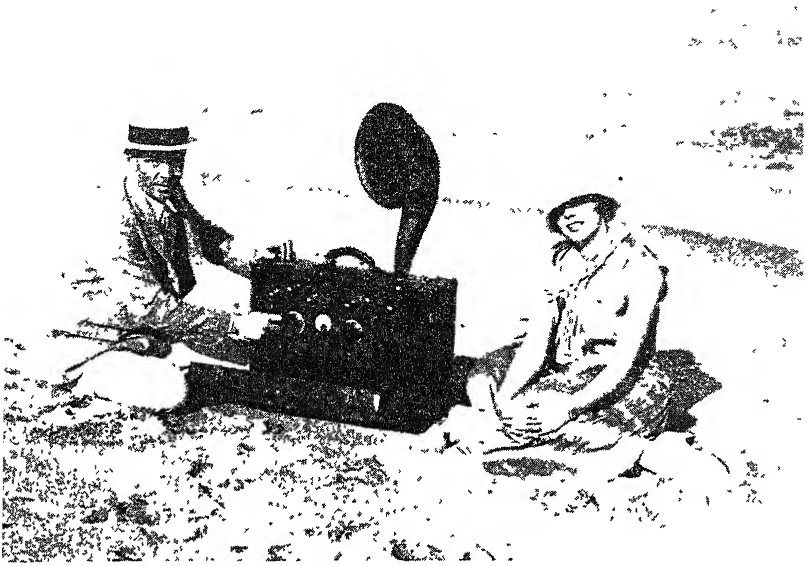
Major Armstrong (*right*), decorated by the French government for his inventions, stands before the Eiffel Tower in Paris, 1919, with General Ferrié, chief of French military communications, an unidentified U. S. officer, and Professor Abraham of the Sorbonne



George Burghard

Ewing Ga

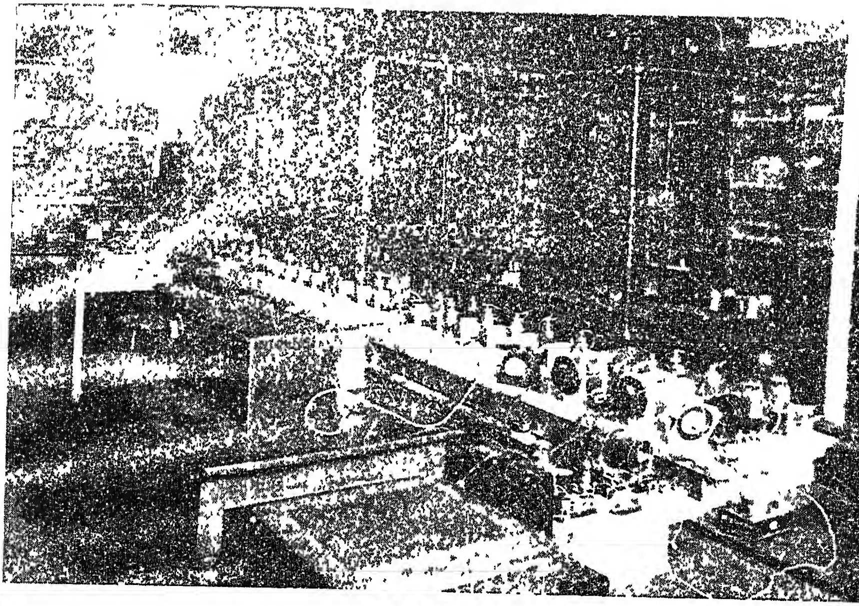
Out of the Army and ebullient on the first wave of radio broadcasting in th
Mad Twenties, Howard Armstrong, Assistant Professor of Electrical En



European

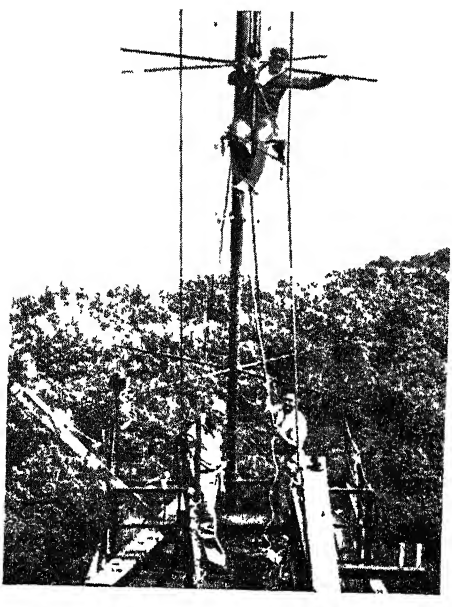
Married on December 1, 1923, Howard and Marion Armstrong went to Palm Beach for their honeymoon. Here on the beach Howard tunes in the world's first "portable" radio, a wedding gift to his bride.

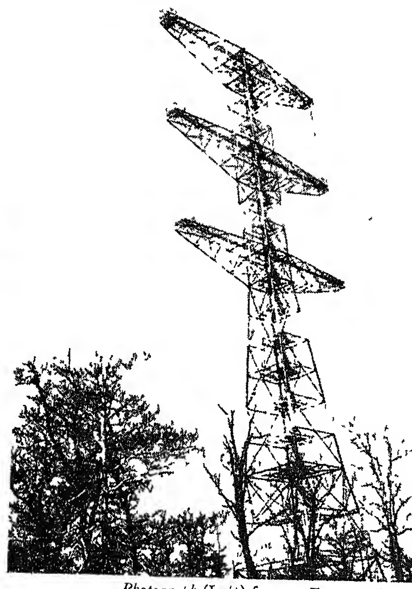
Armstrong (*right*) poses with Guglielmo Marconi, his life-long idol, on the Italian inventor's last visit to the States



J. Boldtm

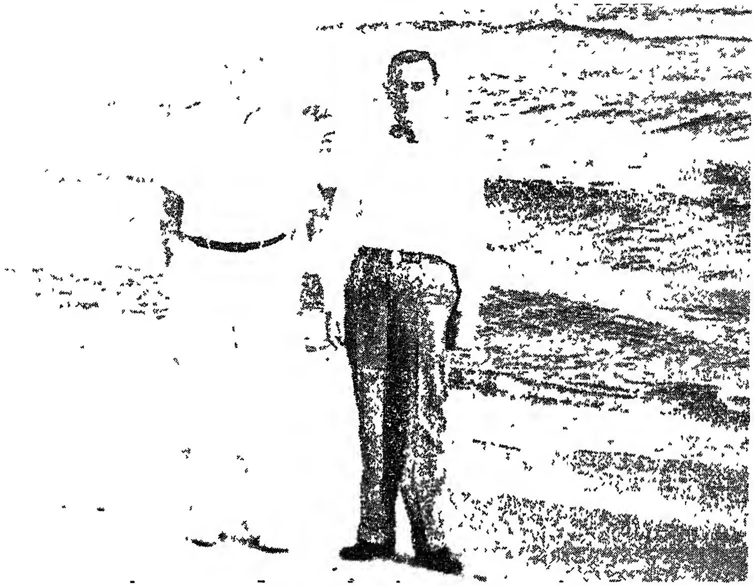
In 1933, after a decade of work and defeat, Armstrong made his third major invention, FM radio, a new static-free system of broadcasting. Above is the circuitry in the basement of Philosophy Hall, Columbia University, which first made FM possible



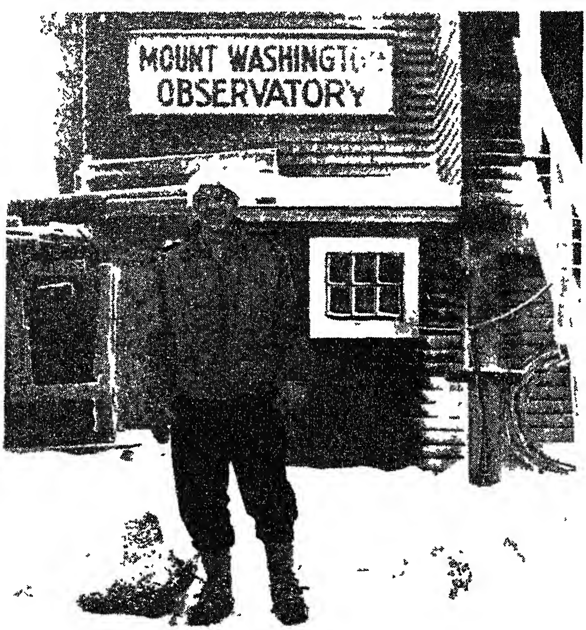


Photograph (Left) *from* *Ewing Gallo*

(Left) Unable to interest the radio industry in FM, Armstrong set



At Rye Beach, New Hampshire, summer, 1939, the Major stands with Paul A. de Mars, chief engineer of the regional Yankee Network, which was opening an FM network to cover middle New England

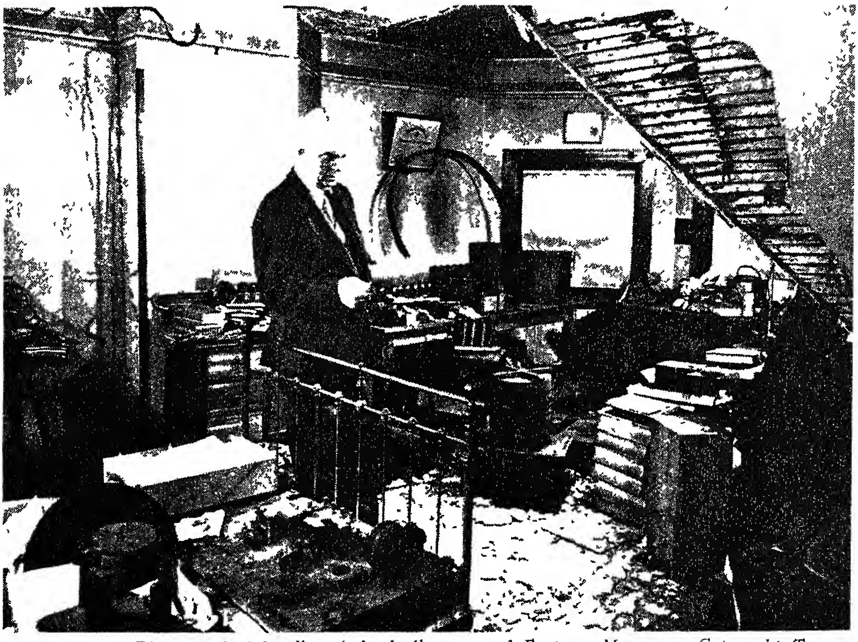


W. T. Tellington, Gorham, New Hampshire

In January 1941 Armstrong for a lark climbed to the top

Newspictures

In 1947, delivering a paper before the American Institute of Electrical Engineers, Armstrong strikes a pose familiar to the engineering fraternity for nearly half a century



Photographed by Eric Schaal, Courtesy of Fortune Magazine Copyright Time I

In 1948, for the purposes of a magazine article, Armstrong

Fabian Bachrach

EDWIN HOWARD ARMSTRONG
American inventor 1890-1954

above 30 megacycles, the then so-called ultra-high-frequencies, where much activity was stirring in spite of its characterization as a no-man's land. Only two witnesses appeared to lay before the Commission the values and needs of FM—Armstrong and a slight young man named Paul A. de Mars, who, as chief engineer of a small independent chain of New England radio stations known as the Yankee Network, was enthusiastic about the possibilities for expansion in FM.

R.C.A. was present in force at the same hearings, represented not only by President Sarnoff but also by C. B. Jolliffe, who was now on the other side of the fence. And it quickly became clear for what purposes Jolliffe had been hired. He now headed R.C.A.'s frequency allocations committee, whose task was to get from the FCC's engineering department, which Jolliffe had just left off heading, the best possible frequency allocations for television. Both Jolliffe and Sarnoff managed in the course of long presentations on the future of the ultra-high-frequencies not to mention FM or any of the FM data accumulated in the long Empire State tests. Yet Sarnoff gave the Commission his open-faced assurance: "We are pleased to place at your disposal the information and experience of R.C.A., gained from its operations in radio research, communications, broadcasting, manufacture and sales." But R.C.A. was patently interested only in television.

At this callous evasion of the most important new development in radio since the founding of the industry, the twenty-five-year friendship between Armstrong and Sarnoff was finally sundered beyond repair. Scarcely two years before, Sarnoff had addressed a letter to him affectionately urging him to direct his energies toward the future of radio, and this was Sarnoff's regard for that future.

R.C.A., of course, was under no compulsion to mention or promote FM. It might have been argued that R.C.A. had some public or moral responsibilities in the matter, owing to the peculiar quasi-governmental creation of its enormous

patent powers, but these were quite indefinite. As a private corporation, it was free to reject FM and to back TV, a more glamorous development with a potentially larger return on investment. But great scientific innovations pose a challenge that is not to be evaded by commercial or political rationalizations, prayers, slogans or softsoap. And FM was that kind of innovation. It challenged the whole basis of radio communications, including television, and challenged it on the basis that radio, with less than twenty years of industrial development behind it, must still be open to improvement.

There was, in fact, a sharp division of opinion within the corporation over FM, with a vast interchange of memoranda, letters, reports and internal statements. But the forces for FM, largely engineering, could not overcome the weight of strategy devised by the sales, patent and legal offices to subdue this threat to corporate position. For FM, if allowed to develop unrestrained, posed a vast number of new radio stations, a complete reordering of radio power, a probable alignment of new networks, and the eventual overthrow of the carefully restricted AM system on which R.C.A. had grown to power. In the end, the decision was David Sarnoff's. As the man who had put R.C.A.'s powers together with great shrewdness and vigor, he had now come to rule the company with plump Napoleonic force and immense vanity. There was to be no rush to get FM into production, as the superheterodyne had been rushed into production in 1923, for Sarnoff was now secure in his power and ready to defend it.

It was to be another personal war, but a war into which Howard Armstrong could jump with great gusto, for in all the early stages it was a technical war with weapons he knew. And involved in the issue was the exposure of error, an exercise in which Armstrong had high talents and no restraint when basic principles were at stake. It was important to his mind to prove whether a single corporation, by its action or

inaction, could keep from the American people a major invention or dictate the speed and sequence with which inventions are introduced.

As early as the spring of 1935, Armstrong, seeing the drift of things, had begun to enlarge his laboratory staff for the task of developing FM into commercial form himself. This was a task requiring large funds and research teams, and it was properly the function of large industrial laboratories. Fortunately, Armstrong had the funds and the courage to use them. Starting in 1935, he took on three young Columbia engineering graduates, John Bose, Bob Marshall and Jim Day. Later he took on more, quietly footing their salaries through Columbia's administrative offices. Bose and Marshall were put to work on FM transmitters, Day on receivers, with Armstrong working closely along with them on an intensive development program designed to get FM into prototype form, ready for manufacture, which Armstrong was sure would come.

This was Armstrong's first intimate working with young engineers, and he set about training and developing them with a skill that time and chance only too rarely had allowed him to exercise. To this new generation he was inevitably known, in that amiable yet sad presentiment of time passing, as the Old Man. And for this younger generation, his approach to problems had a curious fascination. At first it hardly seemed possible that this big quiet man, with so few airs and affectations, plain as an old shoe and awkward in dealing with mathematics, could have made all the basic circuit inventions responsible for modern radio. But as problems arose, Armstrong's mind moved with a directness and a sure grasp of principles that never ceased to amaze them.

Armstrong then was only in his middle forties and actually at the peak of his powers. His energy and gusto for the battle ahead knew no bounds. In 1936 the Armstrongs moved to a

more spacious apartment far east on New York's 52nd Street, in a development known as River House, with a fountain-splashing court, a tennis club and a fashionable view of the placid East River. In the atmosphere created here by Marion Armstrong the Major seemed somehow to be placed finally in his Manhattan setting. His study and library were piled high with books, papers and radio apparatus, overflowing into other nooks and corners of the graceful, traditionally appointed establishment. Four-thirty-five East 52nd Street became almost as closely associated with his later personality as 1032 Warburton Avenue had been with his youth.

It was against this backdrop that all his later battles were fought and all his later friends came to know him, though he never lost touch with any of his older radio-amateur cronies. Friends became familiar with taking the little private elevator to the thirteenth floor and seeing the Major lope over the long parquet floor of the entrance hall to greet them. The currents of his life swirled here into a steadily increasing vortex into which friends and associates were drawn, almost willy-nilly. Armstrong had retained the law firm of Cravath ever since his Supreme Court battles, and Alfred McCormack was now not only his personal lawyer but close friend. Armstrong would telephone McCormack and others, such as Burghard, Runyon and Houck, at almost any hour of the day or night. He was often an insomniac and always a great midnight reader of history, railroad lore, court cases and books on mountain climbing and military-naval battles, which he liked to study for their flaws in communications. He also was a very early riser, and thought nothing of calling friends the moment he arose. Rubbing the sleep from their eyes, they would hear the Major's slow, calm voice on the wire: "George, d'you remember that experiment in January 1916 . . ." In dogged pursuit of his single-minded objectives, he lived much of his life on the telephone, particularly as the battle to establish FM widened.

The battle by no means dismayed him. He had read enough history to know that new ideas are rarely established without a struggle. He had been lucky in his earlier inventions, which had moved with reasonable rapidity into a not yet settled industry. FM, he knew, was a different proposition. It reminded him, and he was often to use the analogy, of the ancient battle of direct versus alternating current, which had gone to such lengths that some of the older districts of U.S. cities were still limping along even then on the inferior service of direct current. In January, 1936, he made a somewhat over-optimistic yet shrewd statement in a New York *Times* symposium on the future outlook. "The new year," he said, "will undoubtedly witness the installation of frequency modulation transmitters . . . The sole difficulty which remains to be overcome and that may retard but not prevent the introduction of this service are those intangible forces so frequently set in motion by men, and the origin of which lies in vested interests, habits, customs and legislation."

The first step was to build without delay a full-scale FM station of his own to silence the talk, already drifting down the backstairs of the industry, that FM would not work. The next step was to get the FCC to assign an adequate band of frequencies to experimental FM in which it might have a chance to grow. Until FM could be heard, the talk would go on that if the "leader" of the industry was not interested in FM, there could not be much in it. In pursuit of the first objective, Armstrong scouted the terrain around New York for a suitably elevated station site and found it in a wooded tract high on the Palisades overlooking the Hudson River at Alpine, New Jersey. He cashed in a block of R.C.A. stock and bought the tract. At the same time he blandly placed an order with R.C.A.'s manufacturing division for a high-frequency power transmitter (to save time in building the power end of his transmitter) and for other equipment totaling some

$60,000. He would fight them with their own weapons. He had no financial need to sell his patents this time, but would license and administer them himself. Two years of observing the maneuvers around his first FM tests had convinced him that the industry, given control of these patents, could not be trusted to put them into use.

The moment he requested an FCC license to erect an experimental FM station at Alpine, however, he found himself in a new and labyrinthine world in Washington. Though such licenses were normally issued as a matter of routine to responsible researchers, his request was turned down. An officious assistant chief engineer threw it out with the gratuitous observation that FM was "a visionary development." Armstrong was until the end of 1936 prying an experimental license out of the FCC, and then only by threatening to take his development to a foreign country. When he came to ask the FCC for an experimental band of frequencies in which FM might get started, another obstacle arose. The FCC's engineering department was so loaded down and preoccupied with R.C.A.'s request for television allocations that FM emerged with only a slim 2.7 megacycles, enough for only five FM channels, as against 120 megacycles or thirteen channels for experimental TV. All this may have had nothing to do with an attempt to block FM, but Armstrong soon came to believe that it did.

Television began to cross FM's path early, and loomed large in all its early struggles. Most of the basic discoveries behind television had come from nineteenth century Europe and the university scientists of Germany, Russia and England. These early discoveries included the invention of mechanical picture-scanning techniques by Paul Nipkow and Lazare Weiller of Germany (1884-1889), the development of the first electronic scanning method by Boris Rosing of Russia (1907), employing the cathode-ray oscilloscope tube invented by Ferdinand Braun of the University of Strassburg

(1897), and the demonstration of a workable but mechanical television system by John L. Baird of England (1925).

By the 1920's, however, most of the practical research on television had shifted to the U.S. and the laboratories of the big electrical and communications companies. As early as 1925, R.C.A.'s David Sarnoff had set his company's sights on being first in the commercial development of television. As time went on it became clearer and clearer that only all-electronic television would provide a feasible system. In 1930 R.C.A. acquired, along with its purchase of Westinghouse's radio manufacturing and research facilities, the services of the noted Russian-born physicist Dr. Vladimir K. Zworykin, who only two years before had made one of the key inventions in modern television. This was the iconoscope or electronic camera tube which, by means of a photoelectric mosaic scanned by a beam of electrons, transformed the light images from the studio into signals for transmission through the air to a receiver. Later R.C.A. also acquired, by license, rights under many important television patents held by Philo T. Farnsworth, an independent American inventor who had developed another type of electronic camera tube. With these and other patents of its own, R.C.A. took a commanding position in the television field.

Many problems remained to be solved, however, before television would be ready for full commercial operation. Chief among these was the problem of transmitting television's very broad band of high frequency signals from city to city for network operations. Ordinary telephone wires, which carried radio network programs, did not have the capacity to carry such a broad band of frequencies. A.T. & T. by the late Thirties, in time for television's first network experiments, had developed the coaxial cable, a special cable of complex design capable of carrying multiple telephone messages or radio-television signals. But only a few cities were linked by coaxial cable to begin with, and it was an

expensive, slow-moving development. Both A.T. & T. and R.C.A. were working on alternative radio relay methods. These would provide a series of relay towers across the country, thirty or forty miles apart. By means of highly directional radio apparatus, television programs might be beamed through the air from tower to tower to link cities more rapidly and economically than by coaxial cable.

Armstrong himself had made no direct contributions to television beyond the regenerative amplifiers that were as basic to TV as to radio. His prime field was radio communications, and he was never inclined to poach on any other. Television, moreover, had reached the stage where only large-scale industrial laboratories could carry it forward. But as early as 1935 Armstrong was predicting that FM, as a basic advance in electronic communications systems, was likely to aid in television's development. And, in fact, FM was destined to make a number of important contributions to television, not the least being a solution to television's network transmission problems. Nevertheless, in all the early years Armstrong was to find FM being blocked by TV in an insensate commercial rivalry.

Through 1937 and most of 1938 Armstrong was absorbed in getting his high-powered, 50-kilowatt FM station built at Alpine. There were many delays, not only in getting the transmitter functioning but in plain construction. Typically, Armstrong had projected the biggest antenna mast he could envision for the new station, amply designed to meet any future research needs. He spent days over at Alpine happily swinging about the high steelwork rising on top of the Palisades. When completed, the mast rose some 400 feet in the air, with three huge cross-arms and cat-walks at the top, reached by a long zigzag of stairs. In installing the FM antenna proper between two of these cross-arms, Armstrong was back in his youth dangling from a bosun's chair in thin air. Yonkers lay directly across the river, a huddle of white houses

and green trees in the sun. On clear days he could pick out with binoculars the cupola of his old Warburton Avenue home, still owned by the family, and beside it the place where his first wooden antenna mast had stood until only a year or two before. There was no gainsaying the passage of years. Just as his new tower was reaching into the sky in 1938, his mother died, after a long illness and blindness, at the age of seventy-eight.

Meanwhile, even as the new station was rising, Armstrong was pressing the research work on FM, designed to improve the system to the nth degree. In little over two years he had twelve additional patents on FM issued to him. The most important of these was a patent issued in 1940, and reissued in the same year, that put the finishing touch on the FM system. Whatever small noise still managed to get through the system was concentrated in the very high audio frequencies, producing a slight sibilant hiss in reception. To eradicate this hiss, Armstrong employed a circuit technique known as pre-emphasis and de-emphasis—long used in wire telephony but never before found to be of any value in radio—in an entirely new way to uncover a new principle. He modified the transmitter so as to over-emphasize or distort the swings of the FM wave at the higher audio frequencies. Then he made a compensating adjustment in the receiver to de-emphasize the distorted wave back to its original form. In the course of this he made an extremely complex discovery and invention. He found that if the receiver's discriminator circuit was so adjusted that it had a frequency admission band greater than the width of the frequency swing of the incoming signal—deliberately lessening the efficiency of the receiver—a great improvement in reception resulted. The total effect was to permit reception of overtones without distortion while blanking out high-frequency noise, an effect of wide consequence in communications.

All through this period the only FM station intermittently on the air was Runyon's low-powered amateur station W2AG, which was kept going so that Armstrong could still demonstrate FM to anyone in the industry willing to listen. On the basis of these demonstrations the small Yankee Network, owned and operated by a shrewd New Englander named John Shepard III, decided in 1938 to build an experimental 50-kilowatt FM station of its own, to be erected on Mt. Asnebumskit near Worcester, Massachusetts, to cover the Boston area. About the same time, another independent station operator, Franklin Doolittle of Station WDRC in Hartford, Connecticut, decided to give FM a trial. Doolittle was an oldtimer in radio and he applied for a license to erect an experimental FM station on Meriden Mountain near Hartford. Action was stirring, but so far as the rest of the radio industry went FM was being attacked or ignored.

Wherever Armstrong went, trying to interest possible licensees in FM, he was met with a barrage of talk, one of the staples of industrial warfare. Strenuous efforts were being made to talk down FM. It was not only said that FM would not work, but also that Armstrong's patents would not stand up. He was that "discredited inventor." Moreover, it was said, FM could not do anything that AM could not do in the very high frequencies, which were "naturally free of static." Furthermore, it was said that FM would never get more than the five channels the FCC had allotted it, and this was obviously inadequate for a national service and therefore not worth investing in. It was said that FM was too wasteful of frequencies, too limited in range, too complex and expensive for receiver manufacture. Anyway, ran the final argument, why have a second aural broadcasting service when the first was "good enough" and the coming thing was television?

From one end of the radio industry to the other throughout this period, when no FM stations could yet be heard, R.C.A. was known to be opposing FM, but uttering no word

publically or officially about it. There seemed to be the transparent hope, shared by others in the industry, that if FM were publicly ignored it might wither away or, failing that, might never grow up to amount to anything. While R.C.A. was officially saying nothing about FM, it had a number of research teams quietly trying to work up patents in FM, just in case FM should begin to grow. And though R.C.A. was not lifting a finger publicly to support or promote FM, it was soon engaging Armstrong in interference proceedings in the Patent Office with one of its patent applications—a receiver devised by one of its engineers named Murray G. Crosby—which, after long tortuous argument, was finally decided in Armstrong's favor.

Shrugging off these harassments, Armstrong pressed on in the summer of 1938 to get his Alpine station into preliminary tests on low power. And as these tests got underway, the dam began to break. The giant General Electric Company came out for FM in one of those dramatic developments that illustrate the countervailing forces at work in the American economy. When the giants fight one another, the small man may benefit. G.E. had been smarting against R.C.A. ever since the anti-trust decree of 1932, when it felt it had been maneuvered out of its radio business. It was then moving back in. In 1937 Armstrong had commissioned G.E. to build twenty-five FM receivers at his own expense to have in readiness for his Alpine demonstrations. The head of G.E.'s new electronics division was Dr. W. R. G. Baker, the same man who had once been with R.C.A. and who was still enthusiastic about FM, which now had the added value of being profoundly irritating to R.C.A. When the special order was completed, therefore, G.E. asked Armstrong for a manufacturing license. In December, 1938, G.E. paid the first royalty to be paid on FM, a check for $22.66, which Armstrong promptly put among his mementoes.

When, early in 1939, Armstrong finally got the Alpine

station on the air with full power, the vaporings of the opposition were blown away like night mists before the morning sun. FM performed with a clarity, fidelity and reliability never before heard in radio. It had cost the inventor well over $300,000 to prove the point, but proved it was. With the call letters W2XMN, a great new pioneering signal in radio communications went out on the airwaves.

The historic significance of Station W2XMN has never been widely realized. Armstrong lavished on it all the care and attention to detail of which he was prodigiously capable. With this station, the first full-scale one of its kind, many basic contributions were made to ultra-shortwave communications. In the development of an antenna to operate in this relatively untried region of the radio spectrum, Armstrong spent long days at Alpine making meticulous measurements, observations and modifications in antenna design which added much to the sum of general knowledge in this area. In the development of power tubes and other vacuum tubes to operate at these frequencies, Armstrong acted as a goad. No tubes adequately designed to operate at high power in the ultra-shortwaves were available when the Alpine station was contemplated. Armstrong bombarded tube manufacturers with observations, criticisms and suggestions that gradually drew forth adequate tubes. All this was part of the enormous indirect influence which, over the years, Armstrong exercised on the development of radio.

Station W2XMN had other, more direct effects on the future of radio. Armstrong went to great lengths to make it a new standard in sound broadcasting. He tested dozens of microphones to find the one most capable of transmitting the full tonal range. He sought out the best professional record-playing apparatus available. On the receiver side, he studied loudspeakers, enclosures and acoustics, and had a speaker built to his specifications in an enclosure as tall and slim as a grandfather's clock. The quality of these compo-

nents was critical in demonstrating the high-fidelity sound that FM was capable of transmitting. Many of these components had been lying about for years, played with and advanced by engineers and a few amateur enthusiasts, but almost unknown to the public. The components were not only expensive but quite useless in association with an AM radio system and popular recordings in which all the overtones of sound above 5,000 or 8,000 cycles were cut off. Historically, FM provided the missing link to bind all this advanced sound apparatus together. In the full-throated 15,000 cycles of the W2XMN transmissions that began pouring out of Alpine on regular schedule in the summer of 1939, the age of high fidelity in radio and sound reproduction was born.

When, in that same summer, the Yankee Network's FM station on Mt. Asnebumskit and Frank Doolittle's station on Meriden Mountain began broadcasting on 2 kilowatts, awaiting delivery of full power equipment, a shiver ran through the radio world. On only 2 kilowatts, Mt. Asnebumskit blanketed the service areas of three high-powered AM stations with a clearer signal than any of them could muster. The economic implications for the whole pattern of radio broadcasting in the U.S. were staggering. When FM went on the air with full power, there would be no way—or so it seemed—of stopping the revolution. The new FM stations were momentarily expecting delivery of full-power transmitters from Radio Engineering Laboratories, Inc., the small but technically able firm which Armstrong had defended in his last battle against de Forest and R.C.A., and to which he now directed all FM transmitter orders, not without a certain malicious satisfaction. His friend Runyon still held an option to buy Radio Engineering Laboratories, and Armstrong freely turned over designs and advice to get FM production started. Two weeks after the Yankee Network's FM station went on the air in preliminary tests, R.C.A. quietly applied to the FCC (but not to Armstrong) for a permit to

erect an experimental FM station—five years after the company had been given the first, exclusive preview of FM.

The Yankee Network development contained still another jolt for the big radio interests and the *status qùo*. To get programs up to the Mt. Asnebumskit transmitter from the network's Boston studios, Armstrong and Runyon had built a 110-megacycle relay transmitter, similar to Runyon's W2AG transmitter, to beam programs through the air from Boston to the mountaintop, some 40 miles away, without the aid of telephone lines. This worked so well that by the fall of 1939 the Yankee Network was testing a second FM relay and broadcasting transmitter erected on top of Mt. Washington in New Hampshire, and proposed a third on a mountaintop in Vermont to provide a service out of Boston to cover all northern New England. There was thus being laid an FM network pattern whereby programs could be beamed over large areas from a single high-powered FM station by means of a series of low-powered FM relay stations.

Meanwhile, General Electric had erected an FM station on Helderburg Mountain near Albany, New York, and had made another useful discovery. Two FM stations on the same wavelength, close together geographically, did not interfere with each other. Mobile crews, testing FM reception up and down the Hudson River Valley, found that in fringe areas, where transmissions from Helderburg and Armstrong's Alpine station overlapped, one or the other station popped in clearly on the receiver, never both together, depending on which station's signal was the stronger. Hence it followed that FM stations could be placed quite closely together on the same wavelengths over the country without interference, thus refuting the charge that FM was wasteful of frequencies. G.E. published its findings, along with exhaustive reports on the whole FM system, confirming at long last the results obtained in the Empire State Building tests five years before, still buried in R.C.A.'s files.

From the mountaintops that made a natural site for FM stations Armstrong was cheerfully fashioning a thunderbolt to rip the radio and broadcasting industry wide open. He acquired a mountain for himself in the Catskills, just to have another station site in reserve. There was no knowing to what lengths the opposition would go in trying to stop this development, for FM now clearly posed a threat not only to the big AM networks but also to A.T. & T.'s lucrative wire charges for network broadcasting. The battle now widened on a broad front.

Armstrong saw in the development of FM the opportunity to free the U.S. radio system of oppressive restriction and regulation. An almost unlimited number of FM stations was possible in the shortwaves, thus ending the unnatural restrictions imposed on radio in the crowded longwaves. If FM were freely developed, the number of stations would be limited only by economics and competition rather than by technical restrictions. Small stations and new networks would have a chance to grow, reducing the need for FCC regulation and lessening the domination of the industry by a few corporations. Armstrong likened the situation that had grown up in radio to that following the invention of the printing press, when governments and ruling interests attempted to control this new instrument of mass communications by imposing restrictive licenses on it. This tyranny was broken only when it became possible for men freely to acquire printing presses and freely to run them. FM in this sense was as great an invention as the printing press, for it gave radio the opportunity to strike off its shackles.

Armstrong took up this theme as a personal crusade through 1938 and 1939, journeying up and down the country at his own expense, speaking with inexhaustible energy before innumerable groups, clubs and technical societies. By the fall of 1939, some 150 applications were on file with the FCC for permits to erect FM stations, and FM's five channels

were obviously inadequate for this and future development.

But the opposition never diminished. The press began to ask questions about FM, and R.C.A. and the big networks were forced to speak up. What came forth, however, was merely a shift in tactics, not in strategy, which was still to "talk down" FM. Radio reporters and others got almost the same stock responses from R.C.A.'s Chief Engineer E. W. Engstrom and NBC's O. B. Hanson as from CBS's Paul W. Kesten and other official spokesmen put forward to answer the curious. Yes, they said, FM was an interesting technical development, but not practical, not economically sound and not anything to get excited about. These sentiments appeared far and wide, and a review of the press at the time shows all the arguments against FM neatly marshaled in a concerted attempt to sway public opinion.

Perhaps the most interesting argument, put forth mainly by R.C.A. spokesmen, was that the public was not interested in high fidelity and would not pay the extra price for it. They pointed out that the big market was still in cheap, low-quality table-model radios. Moreover, they said, high fidelity had been tried in a special AM radio and it had failed. The public invariably turned down the treble control and turned up the bass, indicating that it preferred booming juke-box tones to anything approaching high-fidelity reproduction. The spokesmen coined a knowingly contemptuous phrase widely circulated at the time. The public, they said, had a "tin ear." The only fault with this argument was that it was talking about high fidelity through the inherent distortions of the established AM broadcasting system, which was indeed painful to the ear. It was not talking about FM, which eliminated these distortions to make high fidelity palatable. There were so few FM radios, however, that the public could still be fooled about the desirability of high-fidelity sound.

The myth that "the public does not want high fidelity" was to be promulgated for years, mainly to blunt FM's chief

selling point and to discourage the manufacture of FM sets. Armstrong never ceased to combat the myth wherever it appeared. When, years later, a magazine article by A. R. Weil appeared in *Fortune,* asserting that the public actually prefers low-fidelity radios and supporting this with CBS engineering data, by then long discredited, Armstrong promptly rose again to the defense of the human ear.

"What he says, in effect," Armstrong wrote in a long blistering letter-to-the-editor, "is that the renditions of Stokowski, for example, as heard in the concert hall are, in some mysterious way, improved by bringing them to the ear of the listener through the imperfections of a radio set that leaves out half the notes the musicians play, and that this 'low fidelity' is really what the public wants. Carrying this to its logical conclusion, it follows that our concert halls are not properly set up. Acoustic filters should be introduced between the orchestra and the audience to perform the same function that the low-fidelity radio set performs, so that there will be screened off from the audience that part of the rendition which 'shouldn't be there.' How did this folklore 'that the public disliked natural reproduction' come into being? It is one of the most amusing jokes on the 'engineering' profession in decades."

The opposition, however, did not confine itself merely to talk, potent as that weapon is in industrial warfare. Suddenly late in 1939 the battle shifted in a lightning move to Washington, where R.C.A. brought all its power to bear on a request that the FCC give television immediate commercial status by making all the experimental channels assigned to it permanent. There was an element of reason in this request, for television could have been delayed interminably in experimental status, but it also served as a means of blocking FM by completely ignoring its needs. R.C.A.'s request was that television be given permanently the thirteen experimental channels above 44 megacycles assigned to it in 1936.

These channels were immediately above FM's skimpy five channels in the frequency spectrum. To give television all the channels requested, therefore, would have been to box FM in these five channels permanently, with no available frequencies immediately above or below in which to grow. The five FM channels could not accommodate the 150 station applications already on file, much less the additional stations needed to make FM a nation-wide radio service.

Armstrong and the growing forces behind FM, organized into an independent FM Broadcasters Association, descended on the FCC in January, 1940, to fight for FM's place in the spectrum. To get adequate channels for FM was now a matter of life or death. Armstrong, grown sadly wiser in the ways of Washington, attacked with every weapon he could lay his hands on. He produced copies of the confidential engineering reports on FM which R.C.A. had withheld from the FCC in 1936, and he charged that the corporation then as now was trying to block his invention. The Commission was shocked to attention. It had just acquired a new chairman, an able and liberal lawyer named James Lawrence Fly, who went into the whole matter with great vigor. Under his direction the FCC ruled that the matter of television's permanent allocations would have to be held up until FM's needs were thoroughly aired in public hearings, which the Commission set for March of that year.

In the March hearings, R.C.A. suffered a rout of major proportions. In the interim between January and March it had made the tactical error of launching a heavy advertising campaign to sell television sets, which drew the anger of Chairman Fly. Fly charged that this was clearly an attempt to pressure the FCC by selling as many TV sets as possible in the disputed channels, in defiance of the FCC's ruling to hold television in abeyance until FM's case could be heard, and he ordered all television off the air. Fly promptly found himself attacked in the press as a "New Dealer" hostile to

business. In addition, R.C.A. went on to propose in the FM hearings a number of transparent suggestions for changing FM's technical standards—the first of a long line of suggestions "for FM's own good" put forth by the forces that had done nothing to promote FM as a public service. R.C.A.'s chief suggestion was that FM's frequency band width should be cut in half so that FM stations would require fewer frequencies in the spectrum. Since FM's qualities were directly proportional to band width, by mathematical law, this was to suggest that FM's noise-reduction and high-fidelity characteristics be cut in half. A thoroughly angry FCC threw out all these suggestions, threw television out of its No. 1 channel (44 to 50 megacycles) and put FM in, giving FM a total of forty channels in which upward of 2,000 FM stations might be built. In addition, the FCC ruled, when it got around to settling television's standards and allocations, that all television sound channels should be changed from AM to FM, now clearly shown to be the superior aural broadcasting medium. And, though the industry was never to advertise the fact widely, all television sound has been on FM ever since.

Toward the end of the hearings, which extended into April, R.C.A. suddenly veered in a manner that brought startled headlines in the trade press. Apparently accepting the inevitable, R.C.A. suddenly stated that it now believed that FM was ready for commercial development. Behind this public move was an even more startling private move to come to some kind of agreement with Armstrong on his FM patents. A number of overtures were made early in 1940. Chief among them were those made by Gano Dunn, Pupin's old friend and Armstrong's, who was now a director of R.C.A. and took on the role of intermediary. In a quietly arranged luncheon, Dunn suggested to Armstrong that he merge his FM patents with R.C.A.'s in an arrangement whereby R.C.A. would administer the licenses and divide

the royalties between them. Armstrong said he thought this would be illegal. Dunn said, in a statement that Armstrong was later to recount under oath, that he, Armstrong, was making a big mistake if he thought he could fight "anyone so powerful as the R.C.A."

That there was an effort at settlement in the air was clearly shown in a statement by David Sarnoff before a Senate hearing in April, 1940, on R.C.A.'s imbroglio with the FCC over television. In an attempt to turn aside the FCC's fears that the public would not be sufficiently protected against the obsolescence of TV sets if television was prematurely started, Sarnoff boldly stated: "Many of the things that happened in this country have happened as a result of obsolescence—automobiles and other things . . . The best evidence of that which I can give you is this: You have heard of the frequency modulation of Major Armstrong, and I want to say that despite the fact that there are 40 million receivers in the United States on standard bands, not one of which could receive from the frequency modulation system of Major Armstrong, it did not deter a man of his genius and of his inventiveness and of his persistence from going ahead and carrying on research for a new system of sound broadcasting." This unabashed statement, the first that Sarnoff had ever publicly made on FM, was to prove embarrassing in its effusiveness for R.C.A.'s later position, but in 1940 conciliation was in the air, and the statement served the argument of the moment.

In the fall of 1940 a formal offer was made to Armstrong's attorneys by Sarnoff himself. In it he proposed that R.C.A. be given a non-exclusive license under the FM patents for a total cash payment of $1 million, with no payment of royalties. Robert T. Swaine, senior member of the firm of Cravath, replied to this offer in a letter dated December 19, 1940: "Major Armstrong has concluded that it is not possible for him to accept R.C.A.'s offer to purchase for a cash con-

sideration a non-exclusive license under his patents. I am satisfied that there is little likelihood of his changing his mind on this point." Armstrong could not accept this offer for the reason that he already had testified before the FCC that all his licensees were treated alike, paying royalties of about 2 per cent on FM receivers and equipment. To go back on this by allowing one company to have a license without royalties would be a stab in the back to his early licensees who had taken many of the pioneer risks of development. R.C.A. then proposed a license with royalties only up to a certain point, which amounted to about the same thing. Armstrong took the position that if R.C.A. now wanted a license, it would have to take it on the same terms as G.E. and everyone else.

But R.C.A. had a firm policy on royalties. It collected them; it did not pay them. In only one instance had it ever broken this rule, made possible by the stranglehold it had obtained on radio patents in 1919. By curious coincidence, this one instance had occurred even while Armstrong was being sounded out for an FM license. R.C.A., in its anxiety to control all key television patents, had been forced to conclude a stiff license agreement with Philo Farnsworth, backed by a coterie of West Coast bankers. It is related in a biography of Farnsworth, written by his friend and financial backer George Everson, how, when R.C.A.'s representatives gathered in a big conference room in Radio City to sign the final agreement, Otto Schairer, chairman of R.C.A.'s planning committee, signed with tears in his eyes. It was the first time that R.C.A. had ever signed a contract to pay continuing royalties on the use of patents. As for the FM patents, R.C.A.'s legal staff was of the opinion that they were not indispensable to R.C.A., that they could be beaten or circumvented, if it ever came to a test. Meanwhile, R.C.A. made no move to take up one of Armstrong's regular licenses.

Shrugging this off, too, until such time as he was in a

position to test it in the courts, Armstrong devoted himself to the development of FM, which, now unblocked, was moving with the force of a mountain torrent. By 1941 there were over 500 FM station applications on file with the FCC and over twenty-five licensed FM manufacturers. In addition to G.E., Armstrong added Western Electric, Zenith, Stromberg-Carlson, Stewart Warner, Freed Radio and a host of smaller radio-set makers to his list of licensees. R.C.A. and a large group of its licensees remained outside the Armstrong camp, still basically opposed to FM radio, though now required to use FM in all television sound transmitters and receivers. Even the big radio network stations, however, were now tumbling in haste to get FM stations, if only as self-protection, for there was no knowing where FM was going. To a heroic degree, Armstrong had gone far to prove that a great invention cannot be stopped, whatever the delays and harassments imposed on it.

As a kind of flourish to this victory, Armstrong in January, 1941, donned ice-cleats, a parka and a huge woolen cap and climbed to the top of frosty Mt. Washington in New Hampshire to inspect the Yankee Network's FM relay station in operation under the worst icing conditions. In high spirits, the Major telephoned Harry Houck early the next morning from the mountaintop. "Harry," he said, "I'm looking at the most beautiful sunrise I've ever seen." Houck, who was looking bleary-eyed at the New Jersey darkness, was unable to appreciate the spectacle. Armstrong had grown increasingly fond of New England, and Marion Armstrong had had no trouble sometime before in persuading him to buy a big rambling house at Rye Beach, New Hampshire, where they spent holidays and summers, and from which he now watched the FM revolution spread over New England. It was the Yankee spirit and Yankee enterprise, he felt, which had given FM its first chance to show its worth—not the patent lawyers of the New York board rooms, nor the merchandising seers

of Radio City, nor the pin-striped genuises of Madison Avenue—and he developed a deep affection for the region.

Only brief interludes could be spent at Rye Beach, however, for the FM development was crowding all his time. He added two more graduate engineers to his laboratory, Bill Hutchins and Bob Hull. McCormack, his lawyer, already had taken on a young Columbia Law School graduate, Dana Raymond, to aid in handling the mounting FM business. FM stations were rising on all sides. In quick order, WQXR in New York, WHAM in Rochester, WTMJ in Milwaukee, WMCR in Washington and WBNS in Columbus added FM to their broadcasting services. Armstrong gave WQXR—"The Good Music Station" founded and operated by his old friend John V. L. Hogan—its first FM transmitter to make it the first commercial FM station in New York. By 1942 over forty FM stations were in regular operation, and Randy Runyon exercised his option to buy out Radio Engineering Laboratories, which had become a major supplier of FM equipment. At the same time, FM was sweeping the mobile radio field in police, public utility and other special radio communication systems. R.C.A. had once dominated this field, but, still refusing to get into FM manufacture, it now lost hundreds of millions of dollars in orders for mobile equipment. FM by 1942 was beginning to show its power.

Much later, for the benefit of Congressional committees and the press, R.C.A. was to explain its incredible gyrations over FM between 1933 and 1942 in an entirely different manner from that which appears in these pages. Armstrong, this explanation went, only imagined that he had to go out and build a $300,000 station of his own to prove FM's worth. R.C.A., it held, had never turned down FM but was only taking its time in studying all aspects of the matter. R.C.A., it asserted, had collaborated with Armstrong in making his first FM broadcasting tests in 1934, had aided him in getting his first full-scale transmitter and had put forth important

engineering contributions to FM's development. In fact, it boldly asserted, R.C.A. had done more to speed and promote FM than anyone else. Thus, by an art as old as the hills and as new as the latest Central Public Information Office, black was to be made white, and words were to mean anything a vested authority chose to make them mean. But the history of these days will show that wide-band FM might still be a sheaf of dusty papers in the Patent Office if the inventor had not had the courage, the resources and the stamina to take his invention to the people.

Behind all the exciting first growth of FM, however, the thunderheads of war in Europe were casting a shadow of uncertainty over all man's activities and developments. It was a situation curiously and ironically parallel with that which confronted Armstrong just after making his first invention in 1912. Now, with the Japanese attack on Pearl Harbor in December, 1941, war again broke in to change the whole course and flow of his inventions and his life.

Chapter 13

The Second War

THE WAR THAT HAD begun when Hitler's legions rolled swiftly over Poland in September, 1939, was a war quite unlike that First World War of twenty-odd years before. It was a war nurtured on immense apathies and set off by immense betrayals. In the rise of the corporate state in the Thirties a new mechanized tyranny, fashioned jointly by military and industrial power, was loosed bloodily upon the world. There was to be little romantic nonsense this time about the "glories of war" that led to the mass bombing of cities, the mass extermination of peoples and the mass crematoriums. When, belatedly again, the U.S. was plunged into this contest, it was with the grim determination of a man forced to get a dirty job done.

The war put peculiar burdens on Howard Armstrong, for he was no longer the unattached young man who could drop everything and jump into uniform. The war had begun to impinge on him as early as 1939, when the Signal Corps came to him for aid and advice in adapting mobile FM to military communications. Through 1940 and 1941, tenacious of old loyalties, he sandwiched Signal Corps projects into his already crowded laboratories, gratis, proud that he could aid in bringing U.S. military communications up to date. With the entry of the U.S. into the war, however, the whole situation violently changed. All civilian production of electronic equipment was halted for the duration, which meant a dead halt in the FM broadcasting development. Some forty FM

stations were up or building, and these, including Armstrong's Station W2XMN, were to continue broadcasting throughout the war to hold their audience of some 500,000 FM set-owners until such time as FM was free to grow again. But no new stations or receivers were to be built throughout the war years.

This precipitated a real crisis in Armstrong's affairs, for with the halting of FM production all income from that source ended. He had so far earned only $500,000 in FM royalties, against expenditures of well over $1 million of his own money, and his basic patents had only eight more years to run. Nevertheless, with a gesture typically generous and quixotic, he had promptly at the outbreak of war put his FM patents at the disposal of the government, royalty-free for all military purposes. Needless to say, no corporation could afford such a gesture. Armstrong himself could ill afford it, for his laboratories, commitments and running expenses were now large, and there were compelling reasons, not only for the future of FM but for the national defense, to keep his research going. He was pressed by his associates to take up military research contracts on a cost-fee basis to keep his laboratories running. Reluctantly then, because he hated any arrangement that might reduce his mastery in his own laboratory or prevent him from doing things in his own way, he took on that form of contract research by which the government, with brilliant improvisation, was organizing the most potent mobilization of science in history.

Armstrong thrust all thought of the future from his mind and buckled down to the immediate military tasks at hand and to the immensely complex instrument of war that electronics had become. Many of his friends were scattered far and wide on war tasks. McCormack became a colonel in military intelligence on the U.S. General Staff, and eventually director of the Military Intelligence Service and special assistant to the U.S. Secretary of State. Much of Armstrong's

own work in those fevered years remains still in the shadow of military secrecy. Again, however, he was to bring forth inventions and developments as distinguished in style as anything he had done in the past. In a field in which youth had taken over in great numbers and the trend of development was toward such enormous research establishments as the Bell Telephone Laboratories and the Massachusetts Institute of Technology's great wartime Radiation Laboratory, the Old Man was still able to hold his own. At the height of this effort, Armstrong's research staff rose to eighteen with a payroll of $100,000 a year. And his activities spread out from the basement and roof of Philosophy Hall to his station at Alpine, where more laboratories were improvised and the big antenna tower came in handy for the microwave research that was soon absorbing his time.

His laboratories' earliest contribution to the war effort was the adaptation of FM to various forms of mobile military communications. Here the static-free qualities of the system and the possibility of flexibly extending its range by means of relay operations provided a new dimension in field communications for a lightning war of movement. It is still not generally appreciated that, from the earliest stage of the war, every U.S. Army tank, command car, jeep and other vehicle with facilities for short-range communications was equipped with FM, making U.S. armies among the fastest in the field. The dash of General George Patton's Third Army across France in the late summer of 1944, one of the high episodes in the closing months of the war, was made possible largely by FM mobile relay, for Patton was moving too fast for wire-layers to keep up, and a modern army cannot outrun its communications. The Navy was close behind in this development. After the bloody battle of Tarawa in November, 1943, all Navy and Marine Corps amphibious operations in the Pacific were carried forward with FM as the main mobile communication link between ship and shore. Altogether, the

bulk of all mobile ground communications in the war, manufactured in vast quantities by such suppliers as the Western Electric division of A.T. & T., was Armstrong FM.

Armstrong's main contribution in these years, however, was the conception of a new form of radar, which came to fruit much too late to see use in the war. By the time Armstrong took up the problem in earnest, radar already had done yeoman service in the defense of the British Isles in 1942 and a vast development of the same type of radar was under way in the U.S. The story of radar, next to that of the atomic bomb, is one of the familiar epics of the war. The British scientist Robert A. (later Sir Robert) Watson Watt first proposed such an aircraft detection system to a Committee of Research on Air Defense in 1935. How, then, the British physicist J. T. Randall developed a special high-powered oscillator, called a cavity magnetron, to send out heavy bursts of extremely shortwave radiations to sufficient distances; and how, by close scientific and industrial teamwork, a chain of beacon towers was built to ring the island with radar's invisible beams, revealing the approach of enemy aircraft by day or by night—all this is part of published history and has about it an air of Merlin's magic and the *Morte d'Arthur.*

Briefly, the principles of radar were contained in Hertz' original experiments with electromagnetic waves, in which he showed, by means of big concave mirrors and zinc-plate reflectors, that radio waves could be focused on and reflected from objects like a beam of light. In 1924 these principles were first used by Sir Edward Appleton to bounce a radio wave off an ionized layer in the upper atmosphere and calculate the layer's distance above the earth by noting the time it took the wave to return to a receiver. These same principles were to be used to locate and measure the distance of approaching aircraft, but radio waves to be reflected efficiently from such comparatively small objects as aircraft had to be

in the ultra-ultra-shortwaves. It was to the task of devising the instruments to operate in this high and almost unknown region of the spectrum that the British team headed by Watson Watt brilliantly applied itself. Early in the Thirties a number of U.S. investigators had observed that ultra-shortwaves were reflected from objects, and some work was done on it. But when war broke, the British were far ahead in the practical application of these measures, and late in 1940 Sir Robert Watson Watt made a flying visit to the U.S., carrying in his handbag one precious high-powered cavity magnetron, the size of a man's fist, which was the beginning of the main U.S. development.

Basically, nearly all radar used in the war was of one type. Extremely short waves, ranging from 10 meters down to a few centimeters or inches in length, were whipped out of the transmitter in short rapid bursts or pulses a fraction of a second long. This type of transmission was used because more power could then be developed in short pulses than in continuous waves at these frequencies and the sharply defined pulses gave a swift return indication and clear separation of objects in their path. These bursts of high-frequency radiation went out into space like flashes of invisible light and, meeting an aircraft or other object, bounced back into the "eye" of a receiver which, calculating the time taken for a pulse to return, indicated the distance and location of the reflected object. Ranges up to 100 to 200 miles were achieved. Eventually a great variety of apparatus was devised to serve as navigational aids and target-locating eyes for night-flying aircraft and naval vessels of all kinds. In time, microwave radar was so developed that reflected objects were shown as rudimentary pictures on cathode-ray screens of the television type. Nearly all, however, were of the generic form known as pulse radar.

Armstrong moved into this new field, even before the U.S. entered the war, with a quickness of comprehension that be-

lied his years. He was then going into his fifties, but no more disposed to follow the crowd than when he was eighteen. Nearly everyone was working on pulse radar. He therefore took off in the opposite direction in pursuit of continuous-wave radar, specifically continuous-wave FM radar, hopeful as always that in going against the current he would find something that someone had overlooked. Little work had been done on continuous-wave radar because it was held to be inherently slower, less efficient and much less promising of useful results than the pulse type. Armstrong always reacted to such dicta with the stubborn determination to find out for himself. Time and again he had challenged accepted theory to make his greatest discoveries and inventions.

With America's entry into the war there was a sudden opening out of research in all directions, and one of Armstrong's first contracts with the Signal Corps was for an intensive investigation of FM radar. R.C.A. Laboratories also had done work on FM radar, mainly on a simple, short-range, FM radar altimeter for showing an aircraft's distance above ground, which saw use in the war, and R.C.A. undertook research along the same lines for the Navy. For Armstrong, however, it was to be an exploration in quite a different direction occupying him through all the war years and well beyond, secret to everyone except a few high officials and his closest associates. His chief technical assistants in this work were Bob Hull and John Bose, Hull being another young graduate engineer he took on in 1940 as military research crowded in. Their contributions to the radar system he eventually evolved were so great that their names appear along with his own on the covering patents. In the beginning, however, progress was slow. Eventually nearly everyone in the laboratories was involved in the difficult assignment, along with such old standbys as Runyon and Harry Houck. As the clutter of weird parabolic antenna and intricate circuitry

grew, and the staff along with it, difficulties and disappointments mounted.

The war ended in 1945, first with the rout of the German armies in Europe, then with the collapse of Japan under a mighty mushroom of atomic bombs, and still there seemed to be no conclusion to the work on FM radar. Nevertheless, Armstrong persisted. Out of this long effort he was eventually to pluck a workable radar system as revolutionary in its way as FM itself. Its full details cannot yet be disclosed. But the substance of his findings was that the disadvantages of this form of radar (chiefly a relative slowness) are more than made up by one great advantage: continuous-wave FM radar, when properly employed, has a power and searching range far beyond that of the pulse type. Thus, with typical digging to the roots of a problem, Armstrong laid the foundations for a system of long-range radar that fitted into the defenses of a continent in an age of supersonic speeds, when the range of any warning system must be extended as far as possible in order to be of any use. But all this was to come years later, after a last crushing disappointment, with a twist of irony that seemed to be part of the inventor's fate.

At the end of the war Armstrong received the U.S. Medal for Merit—"for extraordinary fidelity and exceptionally meritorious conduct"—over the signature of President Harry S. Truman. Though the words were trite and sententious, and the honor was somewhat diluted by the wholesale nature of its award, there was an aptness of peculiarly personal force in the citation. Armstrong was swiftly to discover, however, that his real reward for fidelity of service and foregoing of all wartime royalties on FM was to be an extraordinary scuttling of the postwar promise of FM radio.

The underlying opposition to FM radio had never ceased. Indeed, if anything, it had stiffened through the war years, for reasons that the competitive situation made plain.

Through the war the Yankee Network's FM broadcasting system had blanketed the New England area with a service that AM stations and big AM network affiliates could not match in quality or coverage. Moreover, a second FM network known as the American FM Network had been organized to link up Armstrong's Alpine station, G.E.'s Albany-Schenectady station, Doolittle's Hartford station and other stations in the New York, New Jersey and eastern Pennsylvania triangle. These stations exchanged programs and linked into the Yankee Network by bouncing programs through the air from one high-powered station to another without the aid or expense of telephone lines. If this could be done with less than fifty FM stations on the air, what would happen when the war ended and many more FM stations were built? The growth of new FM networks, in competition with the big, low-fidelity AM networks tied to telephone lines, would be phenomenal. As the war ended there were over one thousand applications for FM stations on file with the FCC, and G.E.'s electronics division estimated that FM radio sales in the immedate postwar years would reach well over five million sets. But all this was not to be.

The series of body blows that FM radio received right after the war, in a series of rulings manipulated through the FCC by the big radio interests, were almost incredible in their force and deviousness. They would be quite incredible but for the fact that they are all a matter of record in FCC hearings, reports and decisions throughout this postwar era. In the excesses of victory and great material production, it was an era loud, boastful and thoroughly frustrating to the hopes that out of the holocaust might somehow arise a changed and better world. Beneath the bold surface, fear, hysteria and new tensions marked the struggle for power at home and abroad. It was an era in which the individual was whipped and inundated by the gales of opposing forces.

Armstrong suddenly found himself fighting a second battle to preserve FM.

The second battle began as early as 1943, when the FCC, anticipating a great postwar development of the ultra-short-waves for all kinds of services, called upon the radio industry to review its needs and recommend the standards and frequencies required to go ahead with FM and TV. A large technical planning board headed by Dr. W. R. G. Baker of G.E. set up panels of experts in each specialty to bring in recommendations. The FM panel, composed mainly of the pioneers in the development, reached substantial agreement: that FM, with some additional channels for new growth, go forward after the war in the same frequencies in which it had started. The TV panel also concluded that TV should pick up in the same channels where it had left off. These recommendations were approved by the board and presented to the FCC in hearings starting late in 1944.

These hearings set the stage for intricate maneuvers. Early in its deliberations the FM panel had heard a new proposal from NBC and CBS representatives that FM be moved "for FM's own good" out of its prewar frequencies into a much higher position in the spectrum. The reason advanced by the big AM networks for this disruptive proposal was that they feared that FM would be increasingly troubled in its prewar channels by "ionospheric" or sun-spot disturbances —a solicitude that was lost on independent FM station operators. The FM panel promptly called in the country's leading authority on radio propagation, the U.S. Bureau of Standards' Dr. J. H. Dellinger, who declared that such fears were groundless. When FM came before the FCC, however, that body manifested great concern over "ionospheric interference" and heard a number of witnesses on the proposal to shift FM to higher frequencies.

R.C.A., mainly through its FM panel member Dr. Harold H. Beverage, went on the record as opposing the moving of

FM, as it opposed any moving of TV out of prewar channels. But a long string of witnesses, including representatives of CBS, ABC, Cowles Broadcasting, Crosley, Philco, Motorola and Du Mont, urged that FM be moved "upstairs." And there was no doubt that a heavy portion of the industry that had opposed FM from the start was making a concerted attempt, before as well as behind the scenes, to get FM moved. In the closing days of the hearings the FCC produced a witness of its own, one Kenneth A. Norton, a former FCC engineer then employed by the Army Signal Corps, to assert that secret military data supported the contention that FM should be moved from its old band because of "ionospheric interference." The FM panel hastily assembled a committee of authorities on radio propagation to prove that Norton's data was in error. As a subsequent investigation was to reveal, a closed meeting of military and civilian experts showed that it was in error. But a report of this meeting, edited for release by the FCC's staff, mysteriously showed the opposite conclusion. The FCC—which by then had a new chairman in Paul A. Porter, former legal counsel for CBS—already had made up its mind and was not to be deterred by any facts from the experts.

In June, 1945, the FCC ordered all FM radio to be transferred from its old 50 megacycle band, where it had been giving unexampled service since 1940, to a new band of frequencies between 88 and 108 megacycles, where it had neither transmitters nor receivers developed to meet the postwar market. The plain dishonesty of this order was promptly demonstrated when the FCC turned about and assigned the band it had just ordered FM to vacate to television, a service about twenty-five times more sensitive to any kind of interference than FM and which, moreover, was still required to use FM on its sound channel. Later the same band of frequencies was assigned to government safety and emergency radio services, in which interference of any

kind could be tolerated even less than in commercial broadcasting or television. The fact is that none of the "ionospheric interference" predicted for this band ever materialized.

Actually, there were more compelling reasons in 1945 for shifting television upward than for shifting FM. Television's twelve prewar channels were plainly inadequate, everyone agreed, for a nation-wide service. A considerable body of engineering testimony advocated that TV, with its very wide channel requirements, be moved into the ultra-high-frequencies where there was ample room for the large block of channels needed to provide enough stations to cover the country. Needless to say, however, the FCC did not disturb television in its twelve prewar channels. To provide for the future, it merely set aside a large block of frequencies in the ultra-highs for experimental TV, far removed from the lower band in which television was operating. This compromise was to prove a blunder of the first magnitude. R.C.A. took the position that anyone advocating the moving of TV out of its original twelve channels was trying to sabotage the new industry, for such a move would make all its equipment obsolete and delay the postwar start of television. Yet this was exactly what was done to FM radio, under the flimsiest of technical pretexts.

Nor was this the end of the operations performed on FM in 1945. The Columbia Broadcasting System came forward with a plan for FM called "The Single Market Plan," presented in a handsome booklet and brief by its Executive Vice President Paul Kesten, who had been a caustic prewar opponent of FM. And the FCC adopted this plan, too, in its new postwar regulations. Under the plan, ostensibly put forward to increase the number of FM stations, each FM station was to be limited to a single city or market area by having its transmitter power cut back to cover only that area. The plan was as slick as it was transparent, plainly aimed at cut-

ting down the power of the growing FM networks. Under this plan the power of Armstrong's station at Alpine was eventually cut from 50 kilowatts to 1.2 kilowatts, the Yankee Network's main FM station was cut to a third of its former power, and the ability of high-powered mountaintop FM stations to bounce programs from one to the other by relay was severed.

Thus, not only was FM pulled up by the roots and forced to establish itself in an entirely new region of the spectrum—making obsolete its fifty-odd prewar transmitters and 500,000 FM sets in the hands of the public—but in this new region it was to find its new stations so limited in power as to be kept on a starvation diet. In addition, with its relay powers severed, FM was now made dependent on A.T. & T.'s wire services for any network operations it might still find the strength to engage in. The vast concentration of economic power that marked the field of mass communications as it did all others had rolled over FM and crushed it to a shape less threatening to the monopolistic pattern of operations. The effect of these crushing actions upon Armstrong was deep and lasting. At a time when FM should have been ready to go forward on its own power and when the inventor's mind should have been turning to other things, he was forced to continue the FM battle against mounting odds. It was a battle that was to take on an obsessive character and darken his whole life.

Armstrong had counted on the swift postwar development of FM to replenish his treasury, support his laboratories and supply funds for new research. Instead, FM production was to be delayed for two years following the war, while he poured still more of his own funds into the development of FM transmitters and receivers to operate in the new frequency band. Into this second war to establish FM Armstrong plunged with cold indomitable fury. The multiplicity of his problems would have broken a lesser man. He rarely

appeared at his Columbia laboratories any more, but directed nearly all his research by telephone from River House, not having the time to become involved with laboratory visitors and administrative problems. For he was directing not only the FM development and research on FM radar, but also the licensing, promotion and political defense of FM, shuttling back and forth to Washington in an attempt to fight political fire with fire. The immediate postwar market for FM was lost, the millions of replacement sets required to fill the wartime gap in production going to AM radios of a quality even shoddier than that in the Thirties. But within eighteen months of the order shifting FM out of the lower frequencies, FM was again ready to go.

And again FM showed a quality, even with all the artificial restrictions placed on it, that could not be stopped by fair means or foul. To assuage the growing political rumpus over what had been done to FM, the FCC had stated in its annual report: "In our opinion, FM is the finest aural broadcast service obtainable in the present state of the radio art." But FM needed no testimonials from the Commission. By 1947 new FM stations were going on the air at a fast clip and close to 400 stations were under construction. G.E. and other licensees were moving into production of FM sets. Returning from the wars, in a pattern that duplicated 1919 all over again, was a new generation of men who had worked with FM in its military forms, who had some knowledge of its technical superiority and were ready to carry forward its development.

The banner behind which this postwar technical revolution moved was High Fidelity—or "hi-fi," in the lingo of the young technicians who picked it up—the same high fidelity of reproduced sound which most of the big manufacturers of radios and record equipment still maintained the public did not want. At the core of the revolution was FM radio, but surrounding it was a host of old and new developments, in-

cluding magnetic tape recording, brought out of Germany and developed in the U.S. mainly by the Armour Research Institute of Chicago. To assemble a high-fidelity radio and record-playing system, the new amateurs of the art bought separate components from small manufacturers of high quality professional equipment, for none of the radio mass-producers made anything approaching high fidelity. As friends and neighbors heard these amateur systems, more and more people began to assemble their own components, making the startling discovery that for less than half the price of a comparable, splendidly cabineted AM radio-phonograph, as innocent of high fidelity as a juke box, they could get a system vastly superior and clean in tone. To catch this growing "hi-fi" market, Dr. Peter Goldmark, young research chief of CBS and Columbia Records, late in the Forties adapted and improved microgroove radio-transcription techniques into the long-playing record, which promptly became a major element in the high-fidelity boom.

But again, as in the early history of radio in the Twenties, it was not the big companies or so-called leaders of the industry who led the way in the high-fidelity movement. So far as the manufacture of basic FM-AM tuners, amplifiers, record-players, speakers and other high-fidelity components went, a legion of small, obscure companies with names like Browning, Bogan, Fischer, Bell, Pickering, Altec—most of them founded by the maverick breed of old radio amateurs—walked away with the business. These small companies had no big patent departments nor vested interests in AM broadcasting to protect, hence could promote high fidelity and FM without inhibitions. High Fidelity Audio Fairs sprung up in the major cities, where the companies showed their wares to increasing thousands from year to year and where the orthodox radio manufacturers were conspicuously absent in all the early years. By the early Fifties, high fidelity was to grow to a business variously estimated at from $100 to

$300 million a year, depending on how the term "high fidelity" was defined. And by that time the big manufacturers would be loudly bidding for a lush business which they had done little or nothing to found.

But in 1947 FM broadcasting was still strapped by regulations which, for all the initial impetus of FM's growth, could eventually sap and wither its great vitality. Armstrong and the independent FM broadcasters made another attempt to loosen the main restriction by petitioning the FCC to allow FM to retain a few high-powered FM stations in its old 50 megacycles band, which was still not being put to any use, in order to ease the economic problems of FM network or re-broadcasting operations. The American FM Network had been reorganized into the Continental FM Network and was ebulliently linking together as many as forty-one FM stations north of Washington in chain broadcasts. But to do this it had to do most of the linking by high-frequency telephone lines, for which A.T. & T. charged double the rate of ordinary telephone lines. FM's only hope of escaping these charges and restrictions, which put an enormous burden on its networks just struggling into existence, was to get back some of its high-powered mountain stations to relay programs through the air without the need of cables or wires.

In an attempt to beat down the talk still emanating from the FCC's engineering department and the big broadcasters that FM's former 50 megacycle band was "unsuitable" for FM broadcasting, Armstrong in the summer of 1947 made exhaustive measurements of FM wave propagation in this band. He put up two transmitters at Alpine and rented a cottage called "The Dunes" at Westhampton, Long Island, at a cost of $3,000 for the season, from which to make hourly measurements of the transmissions from Alpine. His assistant, John Bose, was ensconsed alone in this listening-post for two months, taking measurements from 8 A.M. to 11 P.M., checking one transmitter against the other—the most

exhaustive measurements of FM propagation ever made, exceeding anything attempted by the industry or the FCC. Armstrong was proving in the only way he knew how, by scientific and irrefutable documentation, that FM did in fact work in the frequencies in which it had been established in 1938 and in which it had first demonstrated the properties of FM to the world.

Nagged at the same time by continued pronouncements that FM was only a limited "line-of-sight" service, unable to get much beyond the horizon, the Major undertook a last large-scale experiment to demonstrate that this just was not so. Like Marconi, his lifelong model, Armstrong intuitively believed that with proper transmitter power very short waves, such as those employed in FM, would travel much farther than theory predicted. Indeed, Marconi in the years just before his death in 1937, was occupied with a series of experiments, largely ignored by the radio world, which in fact constituted his third major discovery in radio-wave propagation: that microwaves could be bent far beyond the horizon. In his last published paper, printed in an obscure Italian journal in 1933 and not resurrected until two decades later, he reported an experiment in which he had received very-shortwave signals out to a distance of ten horizons. Not even Armstrong knew of this paper, but he was aware of Marconi's earlier predictions. Beaming his Alpine transmitter in a great arc at the sky in one of the last high-powered transmissions the FCC would allow him, he sent a mobile crew into the South to try to pick up the signal which he had a feeling would be there. And some 1,000 miles away in Alabama, as his hunch had led him to suspect, the crew plucked out of the air, somewhat attenuated but still clear, the signal from Alpine. Later in 1947 he put on a demonstration with Jansky and Bailey, Inc., consulting engineers, from Alpine to the International Telecommunications and Radio Conference at Atlantic City that year.

With these experiments, Armstrong was making one of the earliest and most dramatic demonstrations of the existence of an entirely new form of radio transmission, foreshadowed by Marconi but not yet understood, which today is known as "scatter" transmission and is the subject of some of the most exciting developments in radio. In 1951 the Army Signal Corps and Collins Radio Company initiated scatter transmissions in a great beam-like arc, 773 miles long, from Cedar Rapids, Iowa, to the National Bureau of Standards field station at Sterling, Virginia. This type of transmission, it was found, bent shortwaves against a layer of atmosphere known as the ionosphere to provide a circuit almost as solid as a telephone line, giving weak but reliable reception all along the arc-like path for better than 99 per cent of the time. Later a second type of scatter, employing different wavelengths and the layer of atmosphere called the troposphere, was discovered for shorter distances (100 to 500 miles) and multiple services. Early workers in this field included the Bell Telephone Laboratories, M.I.T.'s Lincoln Laboratory, Radio Engineering Laboratories, Inc., and Armstrong himself, who co-operated in a number of experiments. Its significance is that it makes possible longer, more economical spacing of FM microwave relay stations for the long-distance transmission of multiple telephone messages, television and other services. And it is being built into the mighty radar warning system known as DEWline, spanning the great arc of U.S. Arctic defenses, as well as into other military communication systems.

But in 1947 the dictum was that for all practical purposes the ultra-shortwaves were limited to the horizon, and neither the FCC nor the big radio industry wanted to hear any scientific facts to the contrary. Both were preoccupied with television and with an internal struggle for power in which business expediency joined with technical half-truths to cre-

ate one of the major engineering botches of the century. The FM petition to retain some high-power stations in its old band was denied, and all Armstrong's careful work went for nothing. Almost at the same time the FCC rendered a last fateful decision on television. In a bitter internal squabble, the argument had been reopened that television should be moved before it was too late out of its inadequate twelve channels into the higher frequencies. And again R.C.A. took the position that anyone arguing these unpalatable truths was anti-R.C.A., anti-television and probably un-American.

Yet the technical warnings were clear, and were to be borne out only too amply and swiftly by events. In a final brief on the FM matter before the FCC in October, 1947, Armstrong made a sweeping attack, from the depths of his knowledge and experience, on the whole manner in which the FCC engineering department was allocating frequencies to both FM and TV. He charged that the whole engineering basis of their placement in the spectrum was unsound. He warned that TV stations in particular were being placed too closely together geographically on the same and adjacent channels in an attempt to crowd as many stations as possible into an inadequate TV band. He pointed out again that beyond-the-horizon transmissions in these frequencies, which he had demonstrated, would cause serious interference between stations, particularly in television, if they were placed too closely together.

That interference, in the form of rippling Venetian-blind effects on television screens, already had begun to appear even with the few TV stations then on the air. Early in June, 1947, a sizzling letter of complaint had been written to the FCC's new chairman, Charles R. Denny, by Zenith Radio's President E. F. McDonald, Jr., onetime radio-amateur, an old friend of Armstrong's and an early and aggressive promoter of FM, then deep in the battle over FM and TV. "The

interference now plaguing television on this band," he wrote, "is trivial compared to what will happen when new stations now authorized take the air . . . Two injustices have been done, and both television and FM have been seriously injured as a result of engineering errors of 1945. Why not face the facts and correct the situation *now,* before further damage is done? You can do so by moving television *immediately* to its ultimate permanent home you have provided in frequencies above 500 megacycles." This letter was buried in the FCC's files, along with an engineering report of the same date by one of its own engineers, turned up later in a Congressional investigation, which warned that television's interference troubles were likely to grow unless allocations were shifted to a sound basis.

All the warnings were ignored. Armstrong's brief was denied, and television's allocations were directed to proceed on the same scheme as before. Three months after rendering this bracing series of decisions, FCC Chairman Denny was hired to be a vice president and general counsel of the National Broadcasting Company, R.C.A.'s subsidiary, at a salary of some $30,000 a year. As a result of this and similar cases, Congress belatedly passed a law designed to restrain federal employees of regulatory bodies from resigning to accept positions in the industry being regulated.

The year 1948 dawned bright and cold, and was destined to be a most eventful year. It was the first year of full television production. Despite all the powerful interests greasing its ways, television had had many technical and economic problems, and stations were slow in rising. By 1948, however, some fifty stations were on the air and more were arriving weekly and television-set sales were taking off on a boom reminiscent of early radio. But again, reminiscent of early radio, chaos descended on the industry in a manner to suggest that it had learned nothing in a quarter of a century. Before the year was out, new TV stations were running into

interference so badly—as predicted—that in September, 1948, the FCC issued a stop order, halting all licensing of new stations until it could find a way out.

And this stop order was to remain in effect for nearly three years, while the FCC and the industry desperately debated how to get out of the difficulties they had created. Some 120 TV stations already up or being built were allowed to continue broadcasting—so that the public was not to be too aware of the difficulties—but over 300 new stations were suspended in mid-air. Thus, in spite of the strident urgency with which television had been pushed, it was stalled anyhow, but stalled at a point where basic engineering mistakes could not be corrected and where only a patch-up job could be done. For by this time the industry had a large investment in the twelve original TV channels and had sold well over a million TV sets capable of receiving programs only in those channels. And no solution could now be entertained that would violate the sanctity of these investments. The effort to find a solution that would retain the original TV band yet solve the problem of interference—only solvable by finding more space for TV in the radio spectrum—tied the experts into knots. One expert, Thomas T. Goldsmith, Jr., chief engineer of Du Mont Television, hopefully suggested, in a proposal that was to be heard recurrently from then on, that television be given FM radio's band, immediately above it in the spectrum, because, he argued, FM would soon be dead. But FM's few megacycles were no solution to TV's problem, and FM was not to be killed off so easily.

Finally, with the industry beginning to accuse the FCC of blocking "free enterprise," the FCC came to the only solution possible within the system in which it operated. The original TV band was kept inviolate. Then a second and much larger band, far separated from the first, was opened in the ultra-high-frequencies—where U.S. television should have started in the first place, where the industry then had no

transmitters ready for use, and where new stations were to be at an economic disadvantage that was to grow steadily worse. For the established stations and all TV sets in the hands of the public were in the limited low band, where the three big television networks, NBC, CBS and Mutual, long ago had lined up all available stations, particularly in the large cities. Most of the new stations and those that had been waiting for a license for over three years, found themselves isolated in the high band with no audience, and so late in starting that they would never catch up. Thus the ultra-high-frequencies were turned into a secondary service in most cities, and large areas of the U.S. were left to struggle along on an unequal and divided television system. There was a depressing sameness to the pattern of things. For FM broadcasting, clipped of its powers of independent growth, was likewise being pressed by every possible means into a service secondary to AM network radio.

The big networks had come up with another idea "to help FM along." This idea was proudly claimed by R.C.A. and quickly followed by other networks. The proposal was that AM network programs be piped out over the networks' FM stations free of charge to advertisers—to put "good programs" on FM at no extra cost. This was a masterly stroke, for it had a generous air, capable of being used with good effect before Congressional committees, while at the same time it embodied a device as ancient in monopolistic strategy as the "loss leader" or the practice of "dumping" goods below cost to eliminate competition. For if FM was thrown in free with AM network broadcasting, the independent FM station and FM network would have a difficult time convincing anyone to pay for FM programs, the independents' only source of revenue. Nothing was better calculated, when added to the drastic reduction in FM transmitter power and confinement to a 40-to-50-mile service area, to prevent FM from standing on its own feet, developing its own programs

to its own high aural standards and providing real competition for the AM networks.

In 1948 Howard Armstrong made a last attempt to free FM. Through all the latest fracas in Washington he had been cultivating acquaintances on Capitol Hill, determined to carry the fight into Congress to see if justice could be done. Inexperienced and naïve in politics, he could find only a few independents like himself to listen to his story. Chief among these was Senator Edwin C. Johnson of Colorado, who had the old Westerner's distrust of the concentration of economic power in the East and was a frequent attacker of monopoly in radio on the floor of the Senate. Armstrong also cultivated the late Senator Charles W. Tobey, the Bible-thumping Senator from New Hampshire, who lived not far from Rye Beach. Armstrong drove over to have luncheon with him one summer's day, and from all accounts the occasion had some of the features of an old-fashioned revival meeting. Out of all this came a Joint Senate and House Resolution—sponsored in the House by Representative William A. Lemke, a Republican maverick from North Dakota —which proposed to order the FCC to restore part of FM's former band for high-power relay purposes.

In hearings on this resolution and in other hearings kicked up in the Senate by Senator Tobey early in 1948 a full record was made under oath of the attempted suppression of FM before the war and the subsequent hobbling of its postwar development. Among the tidbits revealed was the fact that the FCC's public report on the secret meeting concerning "ionospheric interference" in 1945 had been altered before release by a staff member who could not now recall who had told him to make the changes. In addition, a long array of independent FM station operators, engineers and such independent radio manufacturers as Zenith and Stromberg-Carl-

son testified to the long list of injuries and injustices that had been done to FM.

Armstrong himself recounted for the record and under cross-examination, in his drawling voice and earnest, neck-twisting manner, the whole sorry story of FM from the time he had been requested by R.C.A. to take his equipment out of the Empire State Building down to the present. "Then the effort was to destroy FM," he summed it up, "now, since that is impossible, the effort has been to mold the allocation of FM into a form where it will become a network subsidiary, unable to take the leading role which its technical merits would give it if left unhampered by regulation." No one might be presumed to know better than the inventor himself what had happened to FM.

But nothing was to come of all the Washington hurly-burly. The investigative procedures of Congress in matters of this nature are a vast mechanism for getting the facts and scandals into fine print on the record and then forgetting about them. It was becoming increasingly dangerous and naïve for an individual to attack the powers of large corporations. The resolution to return the FM band was buried in committee and no relaxation of the FCC's iron regulations was to be obtained.

Still the initial growth of FM was not to be slowed down for some time. By the end of 1949 over 600 FM stations were on the air, to reach at a peak some 700 stations, from which the numbers were slowly to decline as the strait jacket of regulations squeezed out their economic life. From this initial tide of FM growth Armstrong had collected by 1949 close to $2 million in royalties on FM receivers, whose sales were still slowly rising. But against the large and continuing investments he had put into FM development and the heavy drain of postwar taxes this was no great sum. For he had spent close to $1 million in keeping his Alpine station in continuous operation, he was contributing heavily to the

FM Broadcasters Association and other groups to fight the battle of FM, and he was continuing FM's research development in an attempt to find ways to improve its economic prospects under the strains of regulation. Some time before, he and Bose had started on the development of FM multiplexing, which Bose was to carry on largely alone, by which FM stations would be enabled to superimpose a second broadcasting service on their carrier waves, without interfering with their basic service, to supply music to restaurants, stores and the like, to add to the stations' slim income.

The money that Armstrong was finally earning from FM was going out almost as fast as it came in. Moreover, the royalties collected amounted to only a small part of those rightfully due him on the total of FM radios and TV sets (using FM in their sound channels) pouring out of the industry. Among the bigger companies, only G.E., Westinghouse, Zenith and Stromberg-Carlson were regularly paying him royalties. R.C.A. and a large group of its licensees, unlicensed under the Armstrong patents, still refused to recognize those patents or pay any royalties under them.

Right after the war, most of the Major's close friends, including his lawyer, Alfred McCormack, had urged him to hire someone to manage his licenses and royalties or to incorporate his patent holdings so that an organization could be formed to take over the burdens of commercial development. But the Major was firmly opposed to becoming a corporation. He had always carried on in his own way, and he proceeded to handle licensing and royalties himself, in addition to everything else, in a maze of correspondence, filing and research that mounted ever more staggeringly with the years. There were strong indications as time went on that some of the companies that refused to take licenses might be persuaded to do so, if royalties were reduced. But the Major refused to reduce royalties. He could be patient and easygoing with his early licensees, particularly the smaller com-

panies which ran into difficulties, never pressing for payment if they were doing a good job. But that part of the industry which had held out for so long was to pay the full rate if it wanted licenses now. As the FM battle mounted and Armstrong's money poured out, it became clear that money was not the object, or was only part of an extremely complex object.

The Major's closest associates urged him to drop the battle and turn to other things, as they saw the toll it was taking. McCormack in particular strongly urged him to compose his differences with R.C.A., reach a settlement—preferably some reasonable annual payment over a period of years to assure himself an income not too deeply cut by taxes—and get on with his research. Immediately after the war R.C.A. had made overtures toward a settlement, and from time to time later on there were indications that some of its people felt that nothing was to be served by prolonging the battle. But Armstrong was always torn between his desire for vindication and a desire to settle the issue so as to have money to carry on his research. What he had set his heart on long before was to make FM the new standard broadcasting system, in defiance of all the corporate forces that had harassed his inventive life. If FM had been allowed to challenge AM on an equal, free and competitive basis, it would long before have begun to supplant the older system of broadcasting. Again it seemed incredible to him that in this country, by means of restrictive regulations and slippery measures, a superior scientific advancement could be overwhelmed by the shoddy and expedient. This was deserving of a test no matter how long or harrowing. The clear and perhaps visionary goal in his mind was still to overturn the restrictions of the old system for a new freedom and fidelity in radio.

The demons of frustration, however, that had plagued nearly all his creations, still rose in ever-increasing clouds. Behind the refusal of a great part of the industry to recognize

his patents was a continuing attack upon their basic validity. Though Armstrong was recognized in every country of the civilized world as the inventor of wide-band FM, the first man to make this system of modulation work in a practical way, still the legal departments in the industry never ceased in trying to whittle away his achievement. First they denied that wide-band FM was an invention at all or patentable as such. Then they attacked the parts of the system as having roots in the prior art and as being reproducible by means other than those circuit arrangements on which Armstrong's patents rested. The effort, as in previous attacks on nearly all his patents, was to deny that Armstrong was the inventor of anything.

Yet the communications industry, which had found no way to use frequency modulation prior to 1933, was now using Armstrong's FM system on an ever widening scale. As early as 1936 Armstrong had predicted that FM would supply, in addition to a new broadcast service, the superior relay system for beaming multiple services, including television, over the country, as demonstrated in his early Empire State tests. In 1940, reviewing the history of FM and the Yankee Network's new FM relay operations, he predicted: "The future undoubtedly will see the introduction of chains of relaying stations equipped with highly directional antenna arrays operating on frequencies considerably higher than those used in broadcasting." All this was largely ignored. A.T. & T. was then pushing its coaxial cable development for the point-to-point transmission of multiple telephone services, radio and television. And it was working on a microwave relay system of its own to supplement the expensive coaxial cable installations as television grew. But this system, after much experimentation, did not work. It was the late Forties, therefore, before A.T. & T. turned to FM microwave relay, based on the Armstrong system, and it was this system that became the basis of the continent-spanning chain of relay towers

which today forms the backbone of television network operations and much else.

Throughout this period Armstrong's relations with A.T. & T. had changed for the better. A.T. & T.'s Western Electric division had been among the earliest of his licensees under the basic FM patents. And the company had sought and received special licenses to erect a number of simple FM relay links to connect such places as Cape Cod, Vancouver and Catalina islands to the mainlands. On all these licenses royalties were paid. But Armstrong was careful to reserve out of these licenses the field of public service communications, such as would be involved in a nationwide FM microwave relay system, on which he hoped to collect a toll-charge type of royalty based on mileage or some other measure. Since A.T. & T.'s FM microwave system was developed in an experimental way only a few months before Armstrong's basic FM patents expired in 1950, however, the problem of royalties became complex. There was a question as to the extent to which Armstrong's patents covered the system as finally developed, if at all. A.T. & T. indicated a willingness to pay a fair sum in settlement, but no toll charges. Armstrong again was torn between making a settlement or pressing for more lucrative returns, and he could reach no conclusion.

More pressing to his mind was the patent situation on FM radio and receivers that had developed with R.C.A. and a large group of its licensees. All these companies were using FM and making FM receivers based on patents developed by R.C.A. Since 1936 R.C.A. had been busy building a patent structure of its own in the FM field. In 1944 it had announced the development of a new type of FM receiver by one of its engineers, George L. Beers, eliminating the limiter circuit and embodying "an entirely new system of FM, disassociated completely from that devised by Major E. H. Armstrong." The Beers receiver, however, never went very far. About the same time it put forward a new type of FM

transmitter, devised by Murray G. Crosby, which later was developed to good use in the industry. None of these or subsequent developments involved anything basically new or more than a variation on what Armstrong had first shown the industry in his basic FM patents of 1933.

The development on which R.C.A. was to pivot most of its FM strategy was a receiver circuit called the "ratio detector," devised by Stuart W. Seeley in 1942 but not introduced until 1946, when R.C.A. produced its first line of FM radios, well behind most of the industry. The Seeley circuit was a straightforward development of considerable merit, telescoping the limiter and discriminator stages of an FM receiver into a single circuit stage or tube. As with all such engineering compromises, there was a loss in quality and performance for a savings in cost. But the "ratio detector" was presented in advertisements as "Super-FM." "Super-FM," the texts explained, "is another 'modern miracle' developed by an RCA engineer." And R.C.A.'s legal department went on to claim that the "ratio detector" embodied something entirely different from Armstrong's invention, and persuaded many of its licensees so to regard it.

Armstrong was too busy fighting off the attacks on FM in Washington to get around to the "ratio detector" immediately, but this was one of the crowning affronts in the long, bloody war of FM. In a coldly analytical paper before the Radio Club in 1948 he showed, with measurements, oscillograms and a careful sequence of circuit diagrams, that the "ratio detector" merely combined the functions of limiting and discrimination in a single tube operation, embodying no new principles—an analysis since confirmed in a number of independent technical papers. Not only did it embody no new principles, but it embodied old principles in such a way as to give something less than full FM performance and noise reduction. Armstrong likened it to the old de Forest "ultra-

audion" which embodied less than half of the properties of regeneration.

It is a moot question whether this attempt to circumvent his FM patents and the payment of royalties enraged him more than the lowering of FM quality it propagated. The lowering of quality had begun almost as soon as FM had been forced into production. In 1940, Philco had begun to sell FM sets without a limiter (and without a license under Armstrong's patents). Armstrong took full-page newspaper advertisements warning against the deficient sets, which soon had to be withdrawn from the market on a flood of complaints. Now R.C.A. and a host of its licensees, beginning with such large units as Philco, Admiral and Motorola, were incorporating something less than full FM not only in FM radios but in TV sets—a further and final drag upon the development of FM as the "finest aural broadcasting system."

In 1948, with the basic FM patents having only two more years to run on the seventeen-year grant of exclusive rights to the inventor, Armstrong wearily girded for another and final court battle. In the fifteen years that had passed, he had taken all the original financial and developmental risks in getting his invention into use, and he had earned not so much honor and wealth as incredible opposition, grief and obloquy. If the past was any indication, he could hardly expect much in the way of justice from the government or the courts. But that a powerful corporation should be allowed to go unchallenged in its trampling upon the rights of the individual was a proposition that his stubborn and embattled nature would not admit.

Through the fall and winter of 1947-1948, therefore, Armstrong and his attorneys, led by Alfred McCormack, were again in the thick of preparing a suit for the courts. Armstrong wanted to bring suit not only for infringement of his patents but also for violation of the anti-trust laws. He was prepared to throw the book at the corporations. After sim-

mering through numerous drafts of the suit to be entered, he was finally persuaded to limit it to more legally manageable proportions. On July 22, 1948, he instituted suit in the Federal District Court of Delaware against the Radio Corporation of America and the National Broadcasting Company, charging them with wilfully infringing and inducing others to infringe five of the basic FM patents. This was to be a suit quite unlike his earlier infringement suit against de Forest. In the interim the procedure in infringement suits had been "liberalized" to allow both plaintiff and defendant to explore each other's cases in preliminary hearings before the actual court trial. Designed to bring the trial itself more quickly and openly to the issues, this procedure, in the case of large suits, was also subject to interminable pretrial delays. And Armstrong's suit was one of the largest of its kind ever brought. Under its terms, he stood to win triple damages on all FM and TV equipment manufactured by R.C.A. and its licensees during the full term of his patents.

Chapter 14

The Last Battle

THE LAST POUNDING years of Armstrong's life opened now with a touch of the old bravura. The last scene of battle was laid not in the lofty, musty grandeur of the court room but in the plain business-like offices of Cravath, Swaine & Moore, his old legal counsel, at 15 Broad Street in the towering financial district of Lower Manhattan. Here in a conference room on February 14, 1949, began the preliminary taking of depositions and cross-examination of facts and issues that were to preface the main court action. And here began an endurance contest that was to drag on through the next five years and terminate only with his life. The R.C.A. forces were represented by Cahill, Gorden, Zachry & Reindel and by Davis, Hoxie & Faithfull—the Davis of the latter firm being, by another of those ironic twists in Armstrong's life, the same William Davis who had been his first patent lawyer.

Under the rules of procedure, Howard Armstrong as plaintiff was the first witness to be put in the chair to be examined by R.C.A.'s legal forces. And in that chair he was to be kept for an entire year, like an aging lion set upon by midges, to be pricked and chevvied, ragged and goaded. The deposition began:

Q. "You are the plaintiff in the present action?"
A. "Yes."
Q. "What is your occupation?"
A. "I am an electrical engineer."

Q. "Do you have any other occupation?"
A. "I am a professor of electrical engineering at Columbia University."
Q. "Do you have any other occupation?"
A. "I occasionally make inventions."

It must be remembered that the gentlemen of law were here addressing the man whose basic electronic-circuit inventions had created the industry on which they lived, otherwise the full acrid flavor of the proceedings cannot be savored. It may be said that the gentlemen were only following legal forms, but if these forms nowhere touch life and reality they become mere grisly charades. Counsel then proceeded to take the witness through the minutiae of the FM patents on which he based his claims of invention, particularly the four key patents that issued simultaneously on that singular day in 1933 and the reissue patent of 1940, in all of which, particularly in the coincidence of issue, the defense seemed to see something of a dark portentous nature.

"Of course, you understand, counsel," said Armstrong at one point, in his dry, ironic drawl, "that I am only claiming to have invented something which is a matter of record in the Patent Office some fifteen years ago." And an invention which in the first five years of its existence was ignored or depreciated by that same industry which was now challenging the right of the inventor to his rewards.

The interrogation then shifted to those rewards. And the defense professed to be astounded that Armstrong handled his own licensing, collection and banking of royalties with none of the bookkeeping and accounting paraphernalia of a corporation—"I have too many things to do in keeping things going to bother with accounting books." It then wanted to know, in sessions spreading over many days, how he did his banking, with whom, how he made out deposit slips, handled checks, kept records, reported income taxes,

and what the total of his FM royalties were. It also wanted to know, in more days of interrogation, how he had promoted FM in speeches and meetings across the country, before what organizations, the size of audiences, the type of auditoriums, with descriptions of same. Still another preposterous session was spent inquiring into an oval insignia bearing the words "Armstrong-FM," which some FM licensees carried on their FM sets. Why was it oval, and who had thought of it and why, the defense wanted to know. Of what relevancy all this was to the issues, except as a time-killer and harassment, was never apparent to the rational eye, but behind it was the steady, goading implication that the inventor was somehow up to some wrong in promoting and attempting to make a profit from his own invention.

"It is perfectly obvious," Armstrong flared out, "that all my life I have used the proceeds of one invention to make another one, and anyone who adopts any other policy in this world will not long continue to have the facilities or the ability to do research and make inventions."

Thereupon the interrogating counsel turned his attention to the inventor's long association with Columbia University. Why was he always referred to as a professor of that university in the press and in signatures to articles? Did he have a formal agreement covering his services? "No, only appointment to the chair of Professor of Electrical Engineering and to a seat on the faculty of Pure Science." When was he appointed and by whom? Only a long search dug up the appointive letter of Nicholas Murray Butler to satisfy the defense. How much time did he spend there and what was the nature of his work?

"The basic work that I have done there for over thirty years," exploded Armstrong, "has been to discover new principles and apply them to the production of new results in the radio art. I have succeeded twice in doing things that people said could not be done." But the defense was ap-

parently unaware that the first duty of a university, at least since the Age of Enlightenment, is to harbor, promote and provide facilities for research. The charade went on and on. Why did he at times write letters on university letterheads, at others on his own stationery, and would he produce all letterheads he used for the defense's inspection?

The record became so burdened with outrageous and vindictive irrelevancies that it was finally appealed by Armstrong's attorney, Alfred McCormack, to the ruling Court in Delaware, which summarily cut it off at the end of a year. It then became the turn of Armstrong's legal forces to dig into the R.C.A. record. And in this pursuit McCormack secured from the District Court one of the broadest rulings ever made in a suit of this kind: that the defendants be required to produce from their files every record, letter, report, memorandum and paper having any reference to FM. The interrogation arising from this monumental flood of paper consumed most of the next two years, for plainly developed from the files were all the shiftings, backings and fillings of R.C.A. policy on FM over the years. The defense, growing restless, asked the Court to appoint a special master to sit in on the proceedings in the hope of cutting down the time. And the Court appointed retired Judge P. J. McCook, still alert at eighty and steeped in the wisdom of a long career. But Judge McCook put no block in the way of a full examination of the record, which went on.

The examination covered at exhaustive length R.C.A.'s key executive, patent and engineering personnel. One of the high spots was the questioning of Dr. Harold H. Beverage, who had been among the early R.C.A. experts to witness Armstrong's first FM demonstrations at Columbia, who had written the 1935 confidential engineering report favorable to FM, who had served on the FM technical panel in 1945 which fought against removal of FM from its old waveband, and who was a scientist of high repute and integrity. He

managed, while skirting the legal issues, to put into the record a warm tribute to Armstrong's technical genius.

When it came, however, to questioning the key patent and engineering witnesses on the infringement issue involved in the so-called "ratio detector" or "Super-FM" receiver, the testimony turned to metaphysics. This receiver, it was admitted, received a wide-band FM wave just like all FM waves. And it converted this FM wave into amplitude audio frequencies, as did all other FM receivers built upon the principles Armstrong had first revealed to the world. But "Super-FM" did this converting, it was held, not by means of a limiter and discriminator circuit—the only known physical means of attaining such a result—but by means of a mysterious and almost inexplicable process called "ratio detection."

Not until February, 1953, in the marathon pre-court proceedings did the Armstrong forces manage to get David Sarnoff himself into the witness chair for a few days. He was at ease, smooth and articulate. McCormack, interrogating, courteously suggested that he tell in his own way some of his background, it being assumed that no cross-examination would be necessary to establish whether he was really, by formal vote or appointment, Chairman of the Board of Directors of the Radio Corporation of America. Sarnoff told with some relish how he had started as office boy for the early Marconi Company, carried bags for Marconi and his engineer "Jemmy" Round, occasionally wrapped and delivered "little parcels for Marconi's girl friends." He then sketched his rise in the company from wireless operator to business manager to president, and, growing expansive, elaborated on his early acquaintance with Armstrong—who sat stony-eyed across the table from him.

"We saw each other frequently," said Sarnoff, "either in my office or in my home. We were close friends. I hope we still are. I enjoyed his confidence and I hope he enjoyed mine . . . during those years, having intimate association with

Armstrong, I would say that I probably learned more about the technical operation of receivers and radio from Armstrong than I did from anybody else—but I still don't regard myself as a scientist or an engineer in the accepted term of the word."

Under persistent questioning, however, as to his technical understanding of his engineers' reports on the crucial FM tests from the Empire State Building in 1935 and what technical advice he had followed thereafter, Sarnoff's testimony developed an edge.

"I had as many technical advisers as a dog has fleas," Sarnoff flung out. "In 1936, you know, I had graduated from being a wireless operator or carrying Marconi's bag; I was then president of the corporation and the thing I liked least to do was to read an engineer's report; so I would get things summarized by Schairer, Beal and Goldsmith . . . Schairer kept telling me, as I recall, that varying the degree of swing [i.e., widening the band of frequencies over which FM operated] was not the subject of a patent, even though it is possible that because of Major Armstrong's standing in the art and his great contribution to the art and so on, that a court might feel that it was an invention, and therefore there was an element of risk and doubt which had to be appraised from commercial and public relations standpoints." Moreover, he said, Schairer kept telling him that it was R.C.A.'s staff, not Armstrong, which had discovered the basic law of FM.

As the questioning probed on to find out what exactly was R.C.A.'s role in the discovery and development of FM, Sarnoff exploded. "I will go further," he stated, "and I will say that the R.C.A. and the NBC have done more to develop FM than anybody in this country, including Armstrong."

At this unparalleled assertion, according to one of the lawyers present, Armstrong's eyes flashed a low flame of pure hatred that is always a grave danger in the moral man facing

the imperfections of the world. Sarnoff was merely behaving as a corporate chairman defending a corporate position. But to Armstrong it was now another personal duel to the death, this time between himself and Sarnoff. The attacking legal forces, with millions of corporation dollars at stake, already had been playing on the personal wounds and frustrations of his career like dentists on a hidden cavity. They had not failed early in the proceedings to dwell on his "discredited" invention of the regenerative circuit. Now they lost no opportunity to bear down on the implication that he was not even to be credited with the invention of FM.

Against this position there were arrayed some of the leading scientific bodies of the world, which long since had reviewed and reaffirmed Armstrong's inventive genius not once but no less than three times. In 1941 he had been presented the Franklin Medal, one of the country's highest honors in the mechanic arts, specifically for the invention of the regenerative-oscillating circuit, the superheterodyne, superregeneration and wide-band FM. Of the oscillating circuit, the accompanying report by the Franklin Institute of Pennsylvania stated: "This invention alone would entitle Armstrong to a place with the greatest inventors and benefactors of the art." In 1942 Armstrong had received from the American Institute of Electrical Engineers an honorary lifetime membership (the first of which had been extended to Lord Kelvin in 1892) and the Institute's highest award, the Edison Medal, for the same string of inventions. In referring to the regenerative circuit, the citation noted: "This keystone of radio development was later to become involved in fourteen years of litigation and which, in the end, was decided by lay courts based on errors of fact and judgment which were contrary to the scientific facts." Finally, in 1949, Armstrong was elected a fellow of Great Britain's noted Royal Society for the Encouragement of Arts, Manufacturers and Commerce, of

which Faraday had been a member a century before—a distinction that comes to few Americans and for which there was to be no parallel honor ever granted him in his own country.

In accepting the Edison Medal, Armstrong delivered one of the most graceful and characteristic papers of his career, entitled "Vagaries and Elusiveness of Invention." In a retrospective mood, engendered by the then apparent victory of FM in establishing itself, Armstrong said in part:

"To have belonged to the generation which learned the meaning of volts and amperes when Edison was at the height of his career, to be able to follow in the footsteps of my old instructor—Michael Pupin—who stood here twenty-two years ago, and to have my own work appraised, during these difficult days, as worthy of the Edison Medal, gives it an inspiring meaning that can never be described.

"But on an occasion such as this, when a man looks back over the events associated with his work, there come some sobering second thoughts. For he begins to realize how minor is that part which he himself has played in shaping the events of his career, how overpowering the part played by circumstances utterly beyond his control. The continuous good fortune which has followed me, providing second chances at inventions when the first chance was missed and tossed away, has been all that a man could hope for and more than he has any right to expect."

Nevertheless, such moods were short-lived, for the fog of denial and non-recognition generated by the industry he had helped to create only grew thicker with the years. From the late Twenties on, a vast rewriting of the early history of radio was perpetrated in dozens of articles and books. Various authors in engineering or executive positions with the corporations artfully trimmed the technical facts to the commercial winds. Others followed suit, often unwittingly. The chief period to be glossed over was 1906 to 1912, when the

three-element vacuum tube lay fallow. Any scrupulous account of this period would have shown Armstrong's decisive role in bringing radio to life. But, to suit the corporations' patent position, radio had to be presented as having leaped full-blown from the brow of Lee de Forest and his vacuum tube, dated 1906. Hence there appeared a plethora of such books as Goldsmith's *This Thing Called Broadcasting*, written in 1930 in collaboration with one Austin C. Lescarboura, proprietor of an enterprise known as "The Wordshop—a literary foundry devoted to the moulding of public opinion." In it de Forest's 1906 tube was described as giving rise immediately to "a generator capable of producing currents to any desired frequency . . . an electrical relay or repeater . . . and a magnifier, or amplifier, which could build up sounds to an astounding degree." The same fiction was endlessly repeated, so that few popular histories of radio even to this day contain anything resembling the truth.

Over the years Armstrong filled bulging filing cases with letters to authors, editors and newspapers, futilely trying to keep the record straight. And not merely his own record, but that of Marconi, Fleming, Tesla and Pupin, all of whom, as independent inventors at the birth of wireless, were being subjected to the same kind of corporate devaluation. The powerful corporations by then wanted not only all the profits but all the control and scientific credit as well. Through the Thirties another mighty round of litigation was being fought up to the Supreme Court, by the same corporations that had garroted Armstrong's regenerative invention, litigation that eventually was to knock out Marconi's important four-circuit-tuning patent and that on the Fleming valve, long after both had expired. Armstrong had met Marconi formally only three or four times in his life, but he never ceased to regard the Italian master as one of the great discoverers and inventors of all time. To defend him against the corporate onslaught, Armstrong frequently had his laboratory staff drop everything they

were doing to hunt historical data and records to refute the depreciating campaign. In 1951 and again in 1953 Armstrong delivered two papers on Marconi—the first before the Western Society of Engineers, the second before the American Institute of Electrical Engineers—that embody the most comprehensive scholarly tribute yet paid to the world-spanning discoveries indelibly associated with that name. Armstrong also in 1943 served as pallbearer at the funeral of Nikola Tesla, who had died in almost complete obscurity at the age of ninety-four. Armstrong wrote an eloquent tribute to Tesla in *The Scientific Monthly* for April of that year.

But the same voracious forces were even then attempting to swallow him into the same obscurity. As late as 1951 Armstrong was writing a twelve-page letter in answer to a long nagging letter from an A.T. & T. engineer, whose name is unimportant, who was still quarreling over early regenerative history and making the astounding statement that Armstrong's Columbia demonstrations of 1913-1914 occasioned no "incredulity" because such results had been long known in the art. "Now wouldn't it be in order for you," Armstrong bitterly replied, "with more than one-third century of hindsight at your command, to tell me what receiving system you knew about that you would have used in 1913 to get these transoceanic signals or, in fact, that you might have dreamed of using to get the results that the regenerative circuit produced."

Even as late as 1954, in one of the last letters he was ever to write, appearing in the January issue of *Wireless World,* Armstrong was still trying to combat the glossing over of the years 1906 to 1912, which had appeared again in a careless statement to the effect that the crystal detector had been the preferred detector in wireless until the advent of the de Forest triode tube. As Armstrong pointed out, the crystal was still the preferred detector long after the vacuum tube appeared, for that tube had been stalemated for six years by

an erroneous explanation of how it worked. "It is worthwhile keeping this period of history straight," wrote Armstrong, "because there is an important lesson to be learned from it . . . The lesson is clear—anyone of us with a volt meter and potential divider to apply known voltages to the grid of a triode, and a galvanometer to measure the changes in its plate current, could have started unravelling the 'audion's' mysteries long before we did start—*had we not known too many things that were not so.*"

The history of FM could not be so readily obscured, for it was too recent to respond easily to the glossers and rewriters. Nevertheless, a start was made. While the press generally recognized Armstrong as the inventor of FM, almost none of the engineering texts that appeared in the U.S. following FM's forward surge after 1940 contained a straightforward account of its origins and development. Many texts managed with glacial impartiality to mention no inventor at all; those that did, mentioned Armstrong merely as one developer among many. Most of the authors were connected by title or professional practice with the corporations, and in those circles both Armstrong and FM were known as "controversial" subjects in "litigation," hence to be treated with the utmost circumspection. Not until well after the war did a straightforward account appear in a British text, *Frequency Modulation Engineering* by Christopher E. Tibbs, with a Foreword by Leslie H. Bedford, which bravely started out: "The subject of Frequency Modulation as we understand it today may be considered to date from Armstrong's paper of 1936. It is true that a good deal of knowledge of the subject existed prior to that date, but Armstrong was the first to point out in a truly remarkable paper those peculiar characteristics to which the modern technique owes its value."

Meanwhile, the litigation, still in its pre-trial stages, dragged on and on. Armstrong's routine in those endless

days of testimony and cross-examination settled down to a steady nightmare. Never one to delegate power, he directed and followed every move in the battle that was now become his life. He would arise at two or three A.M. to read transcripts of the previous day's hearings, jot down questions and subjects to be pursued; about ten he would appear in his lawyers' office for a council of war before the session, which began at eleven; then he would sit through the proceedings until they ended at three or four in the afternoon; by eight or nine P.M., after another council of war, an hour-long telephone talk with Burghard or Runyon or Houck, a mighty Old Fashioned or two with Marion Armstrong and dinner, he would be ready for bed and another day. Days on which no hearings occurred were spent in poring over the mass of documents, checking on the research that never ended, catching up on correspondence and pursuing the multifarious details of his life. Thus it went for weeks and months, stretching into years.

From time to time there were attempts, extending to informal discussions and even a drawing up of terms, to settle the dispute out of court. Armstrong's lawyers, who knew well the hazards of fighting such an unequal contest to the bitter end, were disposed from the start to seek a settlement. McCormack in particular, as he saw the increasing drain on the Major's life and resources, felt more strongly than ever that the litigation was a tragedy that should be ended. But Armstrong was dubious of reaching a settlement he could accept. On one occasion, when one of his lawyers unwittingly remarked that putting a question in a certain way might "prejudice a settlement," he rose to say that there would be no settlement. He was always inclined to see things in black and white. Early in the battle he had stated publicly before a body of engineers: "Whether those gentlemen who pretend to learning in the intricacies of the law will ultimately apply the word sinful, non-sinful or perhaps illegal to what

has happened to FM during the past ten years I do not know. What I do know is that the verdict of history will be that a crime has been committed against the radio art." From that position there would be no retreat.

The opposition had been openly saying for some time now, in another of its bits of psychological warfare, that the Major had developed a "persecution complex"—a familiar charge in modern times against victims and minorities who refuse to knuckle under. But there was no doubt that the obsessive strain of battle was doing something tragic to the inventor's life. He had never in all his crowded years taken much time for relaxation. Tennis was a thing of the past, for he had pulled his shoulder out while surf bathing one day in 1940 at Runyon's New Jersey place, and the surgical wiring that eventually had to be performed on it ended all overhead reaching. He had always detested aimless social gatherings, card games and like amiable nothings. At dinner parties he would swiftly retire to his study unless there was a band of old friends to talk wireless and electricity far into the night. Over the years Marion Armstrong had learned to live with this overriding passion, making in part a life of her own, but, without children, it was often a lonely one. Now, with the litigation dragging on and on, all relaxation disappeared and his life closed in with grimmer intensity than ever before.

Early in the battle Armstrong had said to friends in a moment of prophecy and despair: "They will stall this along until I am dead or broke." And as 1953 wore on it was to be only a question of time which would come first. The winter before he had suffered a mysterious ailment, first thought to be a stroke because of a numbness in opposite sides of the body and head, but later diagnosed as probably encephalitis, an inflammation of the brain. It was a curious, far-off echo of childhood vulnerability. He recovered in a month or two, but was never quite the same. He had been dieting to hold

down his weight, and his big, once well-rounded frame now looked unfamiliarly gaunt. He had driven himself almost without surcease in these later years, and the burden of sixty-three years was upon him. Late in the year he appeared at his sister Cricket's home out on Long Island to install a new radio, and he looked close to a breakdown.

Meanwhile, the drain on his financial resources was as great as that on his physical. To all his high fixed expenses at Columbia, Alpine and River House were now added heavy lawyers' fees, endlessly mounting. His income from FM, after the initial spurt, had dropped off to an alarming degree. Most of his FM patents had expired in 1950, and though royalty payments continued large through 1951 they had now been reduced to a mere trickle. FM broadcasting, as expected, was in a bad way. Indeed, all radio was being shaken by the rising, overpowering bonanza to be made in television. Madison Avenue wits were beginning to talk of radio as of an old prostitute that was no longer a paying proposition. Television's new and golden lures were attracting all the Big Money like a poultice. Against the thin fare left on the old AM radio networks, the struggling independent FM broadcasters could muster only long hours of record playing—a flood of good music, classical and popular, peacefully free of too many commercials, but obviously not a paying proposition and not what the "finest aural broadcasting system" was fitted for. With both radio and television controlled by the same big networks, it was foolish to expect any real competition to develop between the old and new mediums. Still, over 600 FM stations kept going, almost twice the number of TV stations, and FM was in no worse plight than new TV stations in the ultra-high (UHF) band.

The plight of these new TV stations and their clamor for relief was eventually to set off no fewer than five separate and almost simultaneous investigations—three in the Congress, one by the Department of Justice's anti-trust division and

one by the FCC itself. Corrective suggestions ranged all the way from a legislative proposal to bring the big television networks under stringent "common carrier" regulations to a final desperate proposal by the FCC that all television be moved up over a period of years into the single commodious band in the ultra-high-frequencies. Testimony had brought out that the continued separation of television channels in two bands would make it economically impractical for nearly 85 per cent of the television spectrum to continue in existence. Thus the country was likely to be more than a generation straightening out the engineering errors in television allocations perpetrated in 1945-47.

The FM situation, like that of ultra-high TV, was one of starvation in the midst of plenty, a common disease wherever monopolistic practices rule. In this fantastic situation, it was not simply a matter of principle for Armstrong to press his suit against R.C.A., but suddenly a plain matter of life or death. His finances were running out. Few except his wife had more than an inkling of the crisis closing in on him, and even she had no knowledge of his financial situation. From the start he had directed his life with the pride, secrecy and shrewdness of a lone wolf. Now, however, unless he could soon begin to collect his due on the wide uses to which FM had been put in radio, television and communications, his old mode of operation was at an end, his laboratories and his research wiped out.

He had had large dreams. He had talked to Bose and his staff of building new laboratories at Alpine large enough so that they would have the luxury of leaving all their apparatus set up to be referred to at any time, for he had always been loath to dismantle experiments, fearing that some idea or observation might thus be overlooked. But all this was contingent on getting through the suit. It did not seem, after nearly five years of pre-trial proceedings, that the main action could be much longer delayed. But so much

was now at stake in winning it, and so deep were the memories of all the imponderables that had lost him his previous court actions, that his mind began to flinch away from this last, irrevocable contest. What if this suit, too, were carried up to the Supreme Court? He could not last so long.

In October of 1953 Bose was putting the finishing touches on the FM multiplex system—designed to give FM stations some additional revenue by allowing them to put a second music or message service on their carrier waves—when Armstrong proposed that Bose's name appear on the patents covering this invention. Bose had done nearly all the work on the development, and the Major wanted him to have the proceeds. Two weeks later he was back with the patents neatly written out, a type of composition in which he had a masterful clarity of expression and in which Bose had had no experience at all. Later in the month, Armstrong presented the usual technical paper and demonstration on the new development before the Radio Club. He was not in his usual good form. In the presentation of scientific papers the Major always had had a style of his own, striving with an artist's sensibility to make even the most difficult matter and most intricate demonstrations appear effortless. That night, however, his speech was halting and all ease was gone. It was destined to be the last technical paper he would ever present.

Early in November Armstrong saw another item settled in his affairs that had been on his mind. In 1948 he had made a grant of $50,000 to the Columbia University Law School to finance a study of court decisions involving complex scientific matters to discover how well law courts were deciding such issues and how justice might be improved. He had never ceased to think about all the mishaps and misrepresentations of scientific fact that had occurred in the now classic regenerative-circuit litigation. In 1953 the committee in charge of the grant finally found the man to direct the study

—John G. Palfrey of Columbia Law School—and the project was moving forward at last.

Late in November a tragic impasse occurred in the long and on the whole equanimous married life that Howard and Marion Armstrong had had together. Her secret and never broached dream was that they might someday retire to a Connecticut farm that she and her sister Marjorie and her husband had rebuilt together, where Howard might build himself a laboratory and continue his work on a less strenuous scale. If the battle continued as it was going, they would clearly destroy themselves. Clearly, to her practical feminine mind, Howard ought to have a thorough talk with his friend and counsel, McCormack, reveal the seriousness of his financial situation to him, terminate the suit on the best possible terms and leave the decision to history. But the words retirement and settlement were alien to Armstrong's strong-willed nature, and against the frustrations and iron commitments of his life they were incitements to rage.

The climax came after a traditional Thanksgiving party, at which the Major annually was in the habit of assembling his old radio friends. In these later years the gatherings had become a pathetic symbol of his life, for it was only from this group of graying amateurs and associates that he could get that instant warm recognition that assuaged somewhat the defeats of time. After a heavy argument and irrevocable clash of wills late that night, Marion Armstrong, sick and heartsore, went to Connecticut with her sister, whose husband had died suddenly the year before, to wait out the struggle that had taken on the dimensions of an ancient and tragic dilemma. Ill and attended closely by doctors, she was advised not to return to River House until the Major had made a full disclosure of his situation to McCormack.

Swiftly in those last months and years the blows of fate had rained down on Howard Armstrong's head with inexorable force. The first and never-to-be-forgotten blow had been

that postwar shift that had hamstrung FM, seemingly forever. In the last year, however, he had suffered blows to his career that seemed the last straws of vengeful fortune. Underlying them all was the growing feeling, expressed in many notes to friends at this time, that he was finished as an inventor, that he would never make another invention, that his life was over.

Zenith Radio, after having paid him over $1 million in royalties over the years, announced that it would pay no more. Of all Armstrong's licensees, Zenith had been among the most aggressive and technically forward-looking promoters of FM receivers. Payments had continued after 1950, when some of the key FM patents expired, but all royalties from other licensees were now greatly reduced and most of the industry had never paid anything. The sharp cutting off of Armstrong's income in 1953, coupled with his heavy running expenses, left him with barely enough to see himself through another year.

Finally, R.C.A., seeming to sense that Armstrong was at the end of his rope, came through with a last offer of settlement that to him was more outrageous than anything that had gone before. This time the terms were put in the form of a one-year option. At the end of that time, if the suit were called off, R.C.A. would or would not make a total cash settlement of $1 million for itself, and $1 million for the rest of the industry, against any liability for infringement by its licensees—leaving Armstrong dangling in air for a year while his subsidiary claims were wiped out by statute of limitations. This Armstrong rejected, as he had rejected the 1940 proposal of settlement for a flat $1 million, for it presented an abasement that he would never submit to or endure.

Thus, as Armstrong's life darkened in these closing months, the sense of rejection that had started innocently many years before with his father's refusal of patent money for his first invention, and that had mounted on his way up

through the Supreme Court and the corridors of government offices and corporations, now swelled to a diapason in the empty and echoing rooms in River House. How many times did they want him to prove that he was an inventor? He had done it not once but time and again. What was a man to do to insure his honor, reputation and fortune in this country? He still talked with his friends at all hours, and kept on with his lawsuit and his research, but with a growing despondency. He would not be consoled by the remarkable stamina of FM, nor by the steadily mounting high-fidelity movement that must someday reopen the whole issue of FM's curbed powers. "They are already degrading high fidelity," he said. The Christmas holidays came and went, and he was still alone in River House. Toward the end of January, 1954, he finally brought himself to have a thorough talk with McCormack, who was shocked at his frame of mind and tried to assure him that a swift settlement with R.C.A. could be reached. He was now ready enough to grasp at such a settlement, but despondent that it could be concluded.

"Major," McCormack finally said, "turn your mind on to your own accomplishments. You have been given gifts as few men have. You will be remembered when the rest of us are all forgotten."

"Al," he replied, "you don't know how little all that means when you have made a mess of your personal life."

A day or so before this Armstrong had visited his laboratories to review the work still being done on multiplexing. He was so little his old vital and decisive self, displaying a remoteness, uninterest and stumbling lassitude, that Bose anxiously inquired after his health. The Major assured him that it was only one of those virus infections going the rounds that winter, but Bose secretly feared he might have had a stroke. Later Bose called to find out whether the Major would attend the Radio Club meeting that night, a Friday, and was relieved to hear him firmly say that he was staying in

to get rid of his cold. Still uneasy, Bose talked to some of his older friends that night about the Major's condition.

Of that fateful weekend no account can be put together except a few telephone calls: with McCormack, to whom he talked every morning of his life, and who called Sunday morning from Washington, where he was held up on a case, to reassure him that he would be back early in the week to devote full time to negotiating a settlement; to Burghard, whose wife was ill in the hospital, and whom Howard promised to call back that evening, but failed to call; to Runyon, from whom he accepted an invitation to drop out for cocktails that afternoon, but never appeared. The rest is inference and the last remaining record.

"Have you ever been a leaf and fallen from your tree in autumn," wrote T. E. Lawrence, another thinker and man of action welded uneasily into a single personality and tired at the end of his strength. The passion that had sustained Armstrong for so many years and the endurance that was more than other men's were alike drained away. The remarkably close-woven fabric of his life stretched behind him, and, do what he might, was raveling out. To the sense of rejection that had run through that fabric like a dark thread were now added remorse and a sense of having maimed his spirit by endless combat, which no man can engage in without suffering some grime to rub off on himself. And who now cared about or even understood all those old battles, so technical in their ramifications and baffling to the popular mind? It was extraordinary how this civilization, which wears out the nerves and makes such exorbitant demands on individual brains, was at great pains to spare the mass of the people any effort to understand the issues raised by scientific advances. For himself, Armstrong was not retreating but simply dropping in the battle. It was the quest that had counted, the drive for some impossible object, the moments, details, devotions, clarities, zests and passions

involved in pursuit of it, and now that these were dissolving his life was over.

Sometime on that Sunday night of January 31, 1954, he wrote a two-page letter to Marion Armstrong which in its full contents must remain in that last private file to which even common men are entitled. Its gist, however, was that he found it impossible to understand how he could have hurt "the dearest thing in the world to me." "How deep and bitterly I regret," he said, "what has happened to us." His solvency was assured, he wrote, especially if the Telephone Company and R.C.A. "come through anywhere near making good . . . for they know they have been using my invention." He wrote of heartbreak and of the time when they were "happy and free." Finally he wrote: "God keep you and the Lord have mercy on my soul."

He was completely and neatly dressed, in hat, overcoat, scarf and gloves. He did not walk out of the door, however, but out of the window, thirteen stories above the street, falling from the last high place to which he would ever climb. His body was found by a building maintenance worker the next morning, lying on a third-floor extension overlooking the river. Above him in the gray February sky the sooty seagulls plied their usual beat over the leaden East River, and around him stood Manhattan's once shining towers, from which all magic had fled, drab and gray in the light of mid-century.

Chapter 15

The Expense of Greatness

HOWARD ARMSTRONG was buried in the small cemetery at Merrimac, Massachusetts, the town in which he had been married some thirty years before. Marion Armstrong desired to return him there, to lie in her family plot, surrounded by the fair New England hills, far from all the bitter associations of New York. There, far from all his battles, his turbulent life was brought to rest, with a simple granite stone marking the spot.

The funeral was held a few days before, on February 3, 1954, in the Fifth Avenue Presbyterian Church in New York. The Rev. Dr. Thornton B. Penfield, Jr., of the First Presbyterian Church of Yonkers, performed the obsequies, and, from long acquaintance with the family, his remarks were penetrating and just. "His mind was brilliant and creative," he said, "but he kept his genuineness, his integrity of spirit." At the services were his widow, his immediate family and some one hundred and fifty friends, associates and colleagues in the fields of radio and education. Heading the list of attendants at the funeral, as reported in the newspapers, was Brigadier General David Sarnoff and other top figures of R.C.A.

The tributes that welled up were many, personal and varied, though marked in the country's leading newspapers by only a dim comprehension of the tremendous role Armstrong had played in the history of American science and invention. His colleagues on the faculties of Engineering and of Pure Science at Columbia University formally me-

morialized him as "one of the most modest of men" and as an "inventive genius whose name will be forever linked with the development of one of the great scientific and engineering advances of our time."

Then the memorial went on courageously to speak of "a far less generally realized, a truly heroic element" in Armstrong's career: "His late years were unfortunately clouded with a battle to secure for the children of his inventive genius the full opportunity to serve mankind. Frequency modulation, in particular, involved a fundamental change in radio broadcasting, and its introduction was resisted, using every possible means, by the older, already commercially established 'amplitude' interests . . . Long and exhausting labor and tremendous stores of patience, energy and effort on the part of this specially gifted inventive genius were unhappily diverted to a seemingly never-ending struggle to secure a chance to live for the products of his ever-active mind. This challenge he met with heroic courage and unflagging determination."

The American press reflected none of these sentiments. It was left for an Englishman, Armstrong's old friend and colleague Capt. Henry Joseph Round, by then a retired veteran of British radio development, to state boldly in *Wireless World* for March, 1954: "Armstrong should go down in American history as one of her great sons, worthy to be classed with Edison, Bell and Westinghouse."

In succeeding days, as the task of closing and clearing the inventor's affairs proceeded, many curious things came to the surface like flotsam over the place where a great galleon had gone down. It was discovered that Armstrong had been paying out some $1,500 per month for years in high-fidelity wire charges between Washington and New York to keep some "live" FM programs, such as the Library of Congress' chamber music series, coming into the New York area over WNYC and his own Alpine station via the foundering FM Continental Network, which had to cease operations at his

death. Also found among his effects was his old Hispano-Suiza motor car, which had been collecting dust and dead-storage charges for years in a Manhattan garage, against the victorious day when he had hoped to rehabilitate it and retrace his honeymoon journey to Palm Beach. It was sold to a collector of vintage automobiles. There were also over twenty-five large filing cases of personal letters, papers and records, a large and historically valuable technical library, which went to the university, and truckloads of instruments and electronic equipment, which had to be disposed of. And locked in the sub-basement of Philosophy Hall and in various cabinets around the laboratories was every original piece of apparatus he had ever built, starting with the first regenerative circuit of 1912, the pick of these going to the Smithsonian Institution.

The ironies that had so colored and seared Howard Armstrong's life did not cease to flow after his death.

On March 6, 1954, pioneer FM Station KE2XCC (W2XMN) at Alpine, New Jersey, went off the air with a playing of Armstrong's favorite music and a closing ceremony presided over by Alfred McCormack, who had the melancholy task of liquidating the estate. The station had been on the air continuously for sixteen years without advertising, had cost nearly a total of $2 million over the years, and was now being shut down for lack of any incentive to keep it going. (The station property was later acquired by Columbia University to become the Armstrong Field Station for Electronic Research.) Other independent FM stations broadcast memorial programs, but no notice was taken by the big radio networks or AM stations of the passing of the man who had made all broadcasting possible.

In the same month, the British Broadcasting Company announced that it was building a high-fidelity FM network to cover all of Great Britain. The British had been slow to take up FM because its engineers, like everyone else, had been ad-

vised in the early years by the U.S. radio industry that there was nothing in this new form of broadcasting. After the war, however, the British decided to find out for themselves. An impartial engineering committee was set up and experimental stations built to determine whether FM or AM in the same frequencies provided the best system of high-fidelity broadcasting. This committee, with no axes to grind, finally made an Advisory Engineering Report to the BBC which came to a simple conclusion: "The AM wide-band system has specific disadvantages and *no advantages relative to the FM system*. For the AM narrow-band system the only advantage is a possible saving in the frequency spectrum required." Meanwhile, West Germany was in process of building an FM network of over 100 stations, whose clarity and superior service quickly found favor over the crowded airwaves of Europe. Thus, nearly twenty-five years after the invention of FM, Europe and other parts of the world have been quicker to get high-fidelity programing on national FM networks than the U.S., which still does not have anything approaching a truly national FM network.

Meanwhile, the FM radar development, on which Armstrong had filed applications for patents in 1947-1948 and which at the time of his death seemed to be lagging, was being pressed forward on a wider scale than ever before in the Columbia University laboratories. It looms now as one of the keys to the future continental defense of the U.S. Late in the spring of 1954, the U.S. Army Signal Corps, in recognition of his many contributions to military electronics, dedicated a museum of early radio apparatus to him at Fort Monmouth, New Jersey, designating it Armstrong Hall.

In December, 1954, the FM infringement suit against R.C.A. was settled by agreement, R.C.A. and NBC paying the Armstrong estate some $1 million—the same settlement that had been proposed to Armstrong himself as early as 1940. It was concluded not without some further pressure

being brought to bear. McCormack made a flying trip to Germany to sell FM rights to Telefunken for a large sum, with which he proposed to continue the suit if no agreement could be reached. The final settlement did not cover claims against R.C.A. licensees, and separate suits are in progress against Philco, Admiral, Motorola and other radio and TV manufacturers. Later settlement was made with other companies covering FM and FM microwave relay. Thus the Armstrong estate may yet recover some part of the royalties due on the hundreds of millions of dollars' worth of FM and TV sets produced without license before 1950. Probably no more fantastic or ironic instance of patent litigation is to be found in the annals of U.S. industry.

In May, 1955, almost as a last fillip to an extraordinary career, the name of Armstrong was added to the pantheon of great men in electricity and communications by the Union Internationale des Telecommunications in Geneva, Switzerland, a body devoted by international charter to the advancement of world communications. Only four other Americans appear on this roster of twenty names: Alexander Graham Bell, Samuel F. B. Morse, Michael Pupin and Nikola Tesla. Armstrong is here placed in the company of such other illustrious names in the science and communication of man as André Marie Ampère, Michael Faraday, Karl Friedrich Gauss, Heinrich Hertz, Lord Kelvin, Guglielmo Marconi and James Clerk-Maxwell.

This is the end of the adventure that began in an attic under the wide American sky at the hopeful turn of the century, and that found itself mired in despair by those collective forces which, growing upon the power of industrialism, pose something alien and inimical to the promise that is America. To see the life of Howard Armstrong whole, in its tremendous mixture of achievement and adversity, prodigality and despair, is to witness the crushing growth

of those forces on a scale new in U.S. history. About the life itself there clings an old-fashioned, intransigently American air, clean and bitter as the smell of oak leaves in autumn. It is one of the great American tragedies of the times.

It is a tragedy that will be rejected and explained away by any means, for it does not anywhere conform to the highly colored optimistic view of America projected by all the advertising arts and their associated shallow pageantry. It may be shown, for instance, that if Armstrong had acted other than as he did, the outcome might have been different. It also may be shown that if Armstrong had been other than what he was, he might have saved himself all grief and despair. There is today a vast consoling literature designed, in this way, to make men more comfortably adaptable to the world, however repulsive that world may be. But unless the world begins in some measure to adapt itself to great men as it finds them, it is in grave danger of finding itself with fewer and fewer of them. There also is today a large body of psychiatry ready to explain in intimate detail how a man, after a life of indomitable courage and achievement, could come to commit suicide. But all this becomes only too convenient a device, in certain hands, for allowing society to evade its complicity in crimes against the individual by putting all the faults on human personality. Armstrong was literally killed by a society on whose terms he strove valiantly and with high principles to serve, but which reneged on those terms and solemn contracts in the end to bedevil, betray and ultimately to destroy him.

"What more does he want?" one of his adversaries asked in a revealing aside at the height of his last battle, an aside pregnant with the cynicism of men to whom one million dollars are as myrrh and ointment cleansing away all sin and sorrow. Hadn't he received enough honors? "He was always able to talk the engineers around to anything," said his adversaries. And hadn't he made close to $15 million all told

from the industry on his inventions? What more did he want? Only the justice and due that this industrial society repeatedly denied him, and without which all the rest became ashes. If this is not understood, then nothing will have been understood.

It may be said that this is only one individual case, and many mitigating factors and some peculiarities of personality may be marshaled to explain away the tragedy. But in one way or another, and in no clearly related way, this is a growing pattern in this century in which the apathy and docility of the people contrast strangely with the enormous violence done to individuals. The number of instances in the sciences, operating on the dangerous frontiers of knowledge, has been mounting for a decade. It takes no great effort to compile the names of a staggering list of eminent scientists who have been harried from pillar to post under the name of security. But whereas most of these cases are clouded by political passions unconducive to clear thinking, that of Howard Armstrong is not veiled by such distractions. Here was a conservative in the best sense, an innovator of a peculiarly American type and a man who, insofar as he was political at all, followed an old-fashioned Republicanism out of the last century. Yet this did not save him.

Armstrong himself was uncompromising to a fault and peculiarly vulnerable to his fate. In the rigorous specialization of modern life, he was a specialist unable to see himself whole or to bring to his trials those broad views which, while they might not have deflected any blows, might have softened his adversities. The qualities of persistence, stubbornness and absolute honesty that made him a peerless researcher and inventor of the first rank, made him inflexible and often inept in dealing with the world. "Because reason was the tool with which he worked," wrote one of his friends, Milton B. Sleeper, in rueful tribute, "he was violently antagonized by the inability or unwillingness of others to reach

conclusions by the same method." The plain truth that the world does not run upon reason eluded him. Many of his legal battles might have been avoided, his friends believe. He had a contentiousness that was exuberantly a part of his character and of the era in which he arose. He did not suffer fools or injustices gladly.

At the end, Armstrong was more isolated than most men of intellect in this industrial society, where the sense of intellectual isolation grows steadily more acute. He claimed no title higher than that of electrical engineer, yet creatively he was something more than a plain engineer and not to be bounded by this limitation. He might more justly have been called a scientist, but this title is more and more jealously reserved to the pure scientist, pursuing knowledge for no immediate practical use, an endeavor so parched of recognition that it develops a snobbery and caste system all its own. Professionally, therefore, Armstrong was isolated in a small group, with little or no communication with the rest of engineering, the sciences or humanities as a whole. The profoundness of this isolation is revealed by the fact that nearly all the honors and recognition he received came from his own specialized group.

In society Armstrong's situation was even more anomalous. He was a conservative, but one who, in the upsetting nature of his inventive genius and in his attacks on corporations, made conservatives profoundly wary and uneasy, unable to place him in the ready pigeonholes of their minds. He also was a radical innovator in the field of science, but for those of the present liberal-radical persuasion generally he had one quality that precluded understanding. He was a millionaire, and in the liberal-radical mythology it is now firmly rooted that no millionaire can ever play hero in the drama of life. Thus, by a combination of character and circumstance, Armstrong was a lonely individual, unallied with any large social group and destined to go his own way.

When the faults and debits are totaled up, however, there remains a great surplus. His only faults sprang from his great virtue and strength of purpose. He was a man who would stand up and battle for principles as he saw them against the powers of the world, however formidable. This is becoming so rare a trait as to be prized above rubies. The self-directed individualist, combative, independent and free, who has been responsible for most of the great advances in human culture and invention, is a breed that is passing, at least in this generation and this glacial period of history.

There is, in fact, no one quite of Armstrong's large, individualistic stature left on the inventive scene. And this is part of the tragedy, for throughout these later years the cry has been insistently rising that the country is urgently in need of more creative minds, that the number of U.S. scientists and engineers is dangerously falling. But a country that ignores or does not honor the root sources of inventive genius is not likely soon to find a solution. The climate, indeed, grows steadily more hostile to free, independent development. It is becoming increasingly difficult, if not impossible, for an individual to amass the kind of money needed today for independent research. The growing government control of science and the growth of giant industrial laboratories combine to swathe research in ever thicker layers of redtape, regulation, conformity and secrecy. Efforts are now underway to impose "self-censorship" on technical journals, in the mistaken idea, exploded by history, that secrets can be kept from anyone but ourselves for any time. This move, added to the already large areas of science closed to publication for over a decade, would close down information across the board. But the first requisite of creativity is free access to knowledge. If Armstrong had been required to undergo a long government examination and produce a writ of clearance in order to secure his first vacuum tube or any

information on it, it is doubtful whether he would ever have made his regenerative invention.

Unfortunately, it is only the stray, non-conforming individual, rubbing by chance and inclination against freely available knowledge, who makes the great discoveries or inventions. Neither big research teams nor giant laboratories nor large research budgets can substitute for one creative mind. Every great product or development of modern industry may be traced to such independent individuals. Only rarely have they been found in the employ of industrial laboratories. Modern radio is built on seven basic inventions—the four-circuit-tuning invention of Marconi, the heterodyne of Fessenden, Lee and Hogan, the vacuum tube of Edison and de Forest, the audio amplifier of Lowenstein, the regenerative and superheterodyne circuits of Armstrong and the high vacuum tube of Langmuir—only the last of which, by stretching the point, could be said to have come out of an industrial laboratory. All the synthetic fibers and plastics, beginning with nylon, which now form a major part of the modern chemical industry, are built on a giant molecular structure discovered and worked out by five independent scientists, beginning with Karl Freudenberg, Herman Mark, K. H. Meyer and Hermann Staudlinger of Germany, and culminating in the brilliant synthesis of the American chemist Wallace Hume Carrothers, who was hired from Harvard University by E. I. du Pont de Nemours & Company to invent nylon and who also, though under entirely different circumstances, was a suicide. Finally, the whole American atomic energy development rests upon the basic work of a group of independent European and refugee scientists, who found asylum here in the Thirties, but who would now find difficulty entering the U.S. under present stringent immigration and security laws. Unless there is a return of the American climate to that freedom, justice and independence for the individual upon which all

creativity rests, there will soon be an end to these achievements, and such men as Armstrong will indeed be a vanishing breed.

Of Howard Armstrong's own place in history, it is now secure beyond the envy and destruction of men. He was not as broad or universal a genius as Faraday, nor was he a profound scientist of that basic type which only Europe thus far has produced in any quantity. He was a practical genius of a kind that up to now has been America's chief glory, and of that kind one of the best, more prolific than Morse or Bell or Westinghouse, deeper and more consistently inventive, in a straight line of development, than Edison. Altogether, his accomplishments are encompassed in forty-two patents and nearly as many scientific papers—no great number so far as quantity goes, but of the highest quality. His regard for the inventive art was so great that he never filed for a patent until he knew exactly what the patent was for and what the invention embodied in it would do. Many techniques and developments, first noted in his earliest records and later patented by others, he regarded as too minor to patent. Altogether, his patents and papers still comprise the basic and essential literature of radio communications.

The lonely man listening to music in the night, the isolated farmer hearing nightly the news of the world, the airplane pilot guiding his craft safely through the ocean of sky, the emergency crew contending with some mission of mercy or disaster, the army on the move and the man in his armchair, charmed or instructed for an hour by a great play, a symphony, a speech, a game of ball—all owe a debt to this man who in forty years of high fidelity fashioned the instruments illimitably extending the powers of human communication. History in its long course may be expected to correct many of the injustices. FM assuredly will some day regain its power to become the standard broadcasting system

of the country and the world, for no superior technique in human culture is ever permanently lost or submerged. And someday a people, grown wiser, will put down the arrogance of monopoly to insure to itself a radio system at least as free as its press. But when that day comes it will be well to remember that in this twentieth century as in all others, these advances were won only at a cost of blood and failure, the expense of greatness.

When the bitterness of these years has passed, it will be seen clearly that Edwin Howard Armstrong was in the great tradition of Benjamin Franklin, who brought down the lightning from the sky on a kite string, and of all those other inspired artisans and tinkers who set out to fashion upon this continent a life more ample and more fruitful in full human development than that under the worn tyrannies of the old world. It is a dream which still has its adherents. In the end, there is a quiet compensation in the fact that Armstrong was never puffed up in his lifetime by the bellows of the modern press and corporations. His life now remains forever intact, individual, stubborn, original, with quirks and depths in it that would have been made to disappear in the official biographies and in the smooth institutional prose of the releases. It is a life which, almost at every point, touches something endless and deep in the human spirit, errant and free, forever untrapped.

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